WaveWatch, an Ambient Information System Displaying Real-time Web Traffic Data

Ben Shelton

Faculty of Science and Information Technology

The University of Newcastle, Australia

THE UNIVERSITY OF
NEWCASTLE
AUSTRALIA

Declaration of Originality

I declare that the work presented in this thesis is, to the best of my knowledge, original and my own work, or otherwise as acknowledged in the text. The material submitted in this thesis has not been submitted, either in whole or in part, for a degree at this or any other university.

Ben Shelton

August 2015

Acknowledgements

I would like to extend my thanks to a number of individuals who have made this research project possible. Firstly, I would like to thank my research supervisor Dr Keith Nesbitt for his constant enthusiasm and guidance through the writing of this thesis. Keith's ongoing support, passion and immense domain knowledge made the writing of this thesis and the creation of the WaveWatch a joy. The learnings and skills that Keith has passed onto me through this process are invaluable.

Secondly I would like to thank Jodie Preston, Jacqui Reed and Gloria Fornasier for offering organisational support for the WaveWatch project. The interest, passion and support from Jodie, Jacqui, Gloria and the wider University of Newcastle Marketing and Public Relations Team, helped see the successful design, implementation and evaluation of the WaveWatch.

Finally as a personal note I would like to extend my thanks to both my Mother Leanne and my Partner Jessie for both being a constant source of encouragement during this research project.

Table of Contents

Declaration of Originality **2**

Acknowledgements **3**

List of Tables **7**

List of Figures **8**

Abstract **9**

Chapter 1 .... **10**

Introduction **10**

1.1 - Introduction **10**

1.2 – Background of the research **11**

1.3 – Purpose of the Research **13**

1.4 – Research Design and Methodologies **13**

1.5 – Summary **14**

Chapter 2 .... **16**

A Review of Ambient Information Systems **16**

2.1 Introduction **16**
2.2 Defining Ambient Information Systems **18**
2.2.1 Tangible versus screen-based displays 21
2.2.2 Levels of Ambience 23
2.2.3 Summary 25
2.3 Motivations for Developing Ambient Information Systems **26**
2.3.1 Increasing Information Awareness 26
2.3.2 Encouraging Behaviour Change 27
2.3.3 Communication 28
2.3.4 Non-business related 29
2.4 Technologies Influencing Ambient Information Systems **29**
2.4.1 Ubiquitous Computing 30
2.4.2 Calm Technology 35
2.4.3 Information Visualisation 36
2.4.4 User Interface Design 38
2.4.5 Information Decoration, Informative Art and Tangible User Interfaces 40
2.5 Classifications of Ambient Information Systems **45**
2.5.1 Intrusiveness, Notification, Persistence, Temporal context, Overview to detail, Modality, Level of abstraction, Interactivity, Location, Content and Aesthetics 46
2.5.2 Notification, Transition, Abstraction 48
2.5.3 Interruption, Reaction, Comprehension 50
2.5.4 Information, Notification, Representation, Aesthetics 51
2.6 Design Patterns for Ambient Information Systems **53**
2.6.1 Categorising previous displays using design patterns 56
2.6.2 A New Design Pattern - Aesthetic Awareness Display 59
2.7 Evaluating Ambient Information Systems **59**
2.7.1 Current Evaluation Methods 61
2.7.2 Invasive Evaluation Methods 61
2.7.3 Non-Intrusive Evaluation Methods 64

2.7.4 Evaluation Attributes 65
2.8 Conclusions 65

Chapter 3 67

Research Methodology 67

3.1 – Research Question 67
3.1.1 - Use of an Ocean Wave Metaphor 68
3.1.2 - The use of three-dimensional graphics 68
3.1.3 - Explore the proposed Aesthetic Awareness Display 69
3.1.4 - Build upon existing knowledge related to evaluation 69

3.2 – Research Design 69
3.2.1 – Choice of Research Design 70
3.2.1.1 – Classic Experimental Design 70
3.2.1.2 - The Laboratory Experiment 72
3.2.1.3 - Cross-sectional Design 73
3.2.1.4 - Case Study Design 73
3.2.1.5 - Summary 75

3.3 Choice of an Instrumental Case Study Design 75

3.4 – Research Method 77
3.4.1 – Structured Interview 77
3.4.2 – Self-Completion Questionnaire 77
3.4.3 – Structured Observation 78
3.4.4 – Summary 78

3.5 – Implementation of research methods 79

3.6 - Conclusions 82

Chapter 4 83

WaveWatch: Motivations, Design and Technical Details 83

4.1 Introduction 83

4.2 Business Motivation 84

4.3 The WaveWatch Design Process 84
4.3.1 Consider Business Requirements 85
4.3.2 Consider Key Design Features 86
4.3.3 Characterise Data 88
4.3.4 Iterative Prototyping Process 91
4.3.5 Design 3D Model 94
4.3.6 Render 3D Scenes 96
4.3.7 Evaluate Display Aesthetics 97
4.3.8 Data Mapping 99
4.3.9 Implementation and Testing of Prototype 104
4.3.10 Deployment 108

4.4 Conclusion 109

Chapter 5 110

Case Study and evaluation 110

5.1 – Research Methods 110

5.2 - Survey Results 112
5.3 Heuristic Survey Results............ 112
5.3.1 - Findings Heuristic Survey............ 113
5.3.2– Summary Heuristic Survey 118
5.4– Perceived Usefulness and Ease of Use 119
5.4.1 – Summary Perceived Usefulness and Ease of Use Survey 122
5.5 - Conclusion 122
Chapter 6 124
Conclusions and Future Work 124
6.1 Conclusions 124
6.2 Future work 126
Appendix A – Self Completion Questionnaire & Human Ethics 128
Appendix B – Survey Results (Raw Data) 137
Appendix C – Survey Paper 146
1. INTRODUCTION 146
2. AMBIENT INFORMATION SYSTEMS 147
3. DESIGN DIMENSIONS 150
4. DESIGN PATTERNS 154
5. AESTHETIC AWARENESS DISPLAY 156
6. CONCLUSION 157
7. REFERENCES (Survey Paper) 158
References 160

List of Tables

Table 2.1: A list of Fully Ambient Information Systems from the literature 24
Table 2.2: A list of Semi-Ambient Information Systems from the literature 25
Table 2.3: Examples of Ambient Displays designed to Increase Information Awareness 26
Table 2.4: Ambient Information Systems that encourage behavioural change 28
Table 2.5: Typical goals used to guide interface design 39
Table 2.6: Examples of the variety of Ambient Media used in Ambient Information Systems 43
Table 2.7: Various Design Dimensions of Ambient Information Systems 45
Table 2.8: Description of each of Ames & Dey's (2002) design dimensions 46
Table 2.9: Nimio's incorporation of Ames & Dey's design dimensions 47
Table 2.10: Idealised models or design patterns used to categorise Notification Systems 51
Table 2.11: Ranking categories used for the four different design dimensions of the taxonomy of Ambient Information System 53
Table 2.12: Design dimension mappings for Symbolic Sculptural Displays 55
Table 2.13: Design dimension mappings for Multiple Information Consolidator 55
Table 2.14: Design dimension mappings for Information Monitor Display 55
Table 2.15: Design dimension mappings for High-Throughput Textual Display 58
Table 2.16: Sculptural Symbolic Displays 57
Table 2.17: Multiple Information Consolidators 58
Table 2.18: Unclassifiable using existing taxonomy 58
Table 2.19: Design Dimension mappings – Aesthetic Information Display 59
Table 2.20: Examples of methods used to evaluate Ambient Information Systems 63
Table 3.1: Key heuristics for Mankoff's Ambient Display evaluation 80
Table 4.1: - Each of the Displacer Object/Noise Shader attributes for the WaveWatch intensity levels. 94
Table 4.2: The parameters of the Wave Deformer plugin 96
Table 4.3: The WaveWatch intensity Levels 103
Table 4.4: The components of the WaveWatch and the technology used to build it 104
Table 5.1: Data collected from the Heuristic Survey 113
Table 5.2: Results Perceived Usefulness and Ease of Use Survey 119
Table 5.3: Responses to the Perceived Usefulness and Ease of Use survey as percentages 120

List of Figures

Figure 2.1: The Information Percolator ... 19
Figure 2.2: A Venn diagram of the domains contributing to Ambient Information Systems ... 30
Figure 2.3: An example of Informative Art ... 31
Figure 2.4: The Water Lamp Display ... 33
Figure 2.5: The Pinwheels Ambient Fixture ... 33
Figure 2.6: The evaluation and non-evaluation of Ambient Information Systems ... 60
Figure 4.1: A UML diagram showing WaveWatch the design and development process ... 85
Figure 4.2: A plot of web traffic data showing typical changes in web traffic over a period of seven days. ... 88
Figure 4.3: A plot of web traffic data showing typical changes in web traffic over 3 days. ... 89
Figure 4.4: Each of the 20 WaveWatch levels presented as a line on web traffic data. ... 90
Figure 4.5: Prototype one of the WaveWatch display ... 92
Figure 4.6: Prototype two of the WaveWatch display ... 93
Figure 4.7: The final prototype of the WaveWatch display ... 93
Figure 4.8: The attributes set on the Noise Shader that was used to create the ocean chop animation on the WaveWatch ... 95
Figure 4.9: The WaveWatch displaying various levels of chop intensity ... 101
Figure 4.10: The WaveWatch displaying an ocean wave. ... 102
Figure 4.11: The hardware and software used to create the WaveWatch. ... 105
Figure 4.12: A UML process diagram showing how the WaveWatch functions. ... 106
Figure 4.13: The WaveWatch being tested on a computer monitor ... 108
Figure 5.1: The WaveWatch display installed into the M&PR office at The University of Newcastle, Australia ... 111

Abstract

This thesis observes the design, development and evaluation of a novel Ambient Information System, the WaveWatch. The WaveWatch utilises high-definition (1920x1080), pre-rendered 3D graphics to display real-time web traffic data. Specifically, the WaveWatch utilises the metaphor of an ocean wave to visualise web traffic volumes. The WaveWatch's metaphor is simple, if web traffic is high the display's ocean becomes larger and more turbulent and if web traffic is low the display's ocean becomes calm and flat. This research investigates both the feasibility of building such a display and the effectiveness of conveying real time information through the novel medium of a dynamic ocean.

The WaveWatch display was developed through an iterative design process, with a number of prototypes being developed before the deployment and evaluation of the final design. Overall it was found that creating an Ambient Information System that utilises 3D graphics and an ocean wave metaphor was technically feasibility. However, building the display was a complicated and lengthy process taking around 200 man-hours. This process was complicated by a number of design challenges including the creation of an aesthetically pleasing scene, the time for each scene to render, the creation of a real-time dynamic looping ocean animation and the limitations of current video playback technology. Despite these technical difficulties it was possible to combine existing technologies to create the novel Ambient Information System known as WaveWatch.

An instrumental case study was performed, where the WaveWatch display was deployed in a real life office environment for a period of two weeks. After this two-week evaluation period, participants who worked in the area were given the chance to complete a questionnaire related to the utility and perceived ease of use of the display. The key finding from this instrumental case study was that the majority of respondents found the novel wave metaphor for peripheral information visualisation to be a useful tool for generating interest in the underlying data source, where the metaphor itself was perceived to be both intuitive and easy to understand.

Chapter 1

Introduction

1.1 - Introduction

Ambient Information Systems, or Ambient displays, are intended as peripheral computing devices that try to visualise useful information seamlessly in the context of one's everyday environment. Ambient Information Systems represent a novel technology that fall within the realm of ubiquitous computing. A typical definition of an Ambient Display is as follows:

"Ambient displays are abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user's attention." (Mankoff et al., 2003)

A number of technologies and concepts from the domains of Information Visualisation, Calm Technology (Weiser and Brown, 1996) and Ubiquitous Computing (Weiser, 1991) are relevant to the study of Ambient Information Systems. Intended as ubiquitous devices that might be present everywhere, Ambient Information Systems are typically designed to be aesthetically pleasing so they can be more easily integrated into a private or public environment and also function without interrupting the user's primary attention. Thus they should be calming rather than disruptive for users.

This thesis aims to expand existing knowledge of Ambient Information Systems firstly through a detailed synthesis of the current domain literature and secondly through the development, deployment and evaluation of a novel Ambient Information System. The WaveWatch display is unique in that it incorporates a new wave based metaphor for visualising real time dynamic information using pre-rendered 3D graphics. As identified in the literature review, the WaveWatch is designed to explore a currently understudied design pattern in the field of Ambient Information Systems. The design pattern that we describe as the *Aesthetic Awareness Display*, is characterised by a high emphasis on aesthetic qualities and a low information capacity.

1.2 – Background of the research

The first Ambient Display, the Dangling String (Weiser & Brown, 1996) was originally described in 1996. Since this time a number of different peripheral devices have emerged that fall under the domain of Ambient Information Systems. These displays usually fall under two categories in terms of their physical nature. Some Ambient Displays utilise the changes to a physical, tangible object for display. A second common type of display relies on 2D visuals displayed on a computer screen to visualise information. This research focuses on the second type of display but explores the use of 3D visuals for peripheral information visualisation on a traditional computer screen.

Although the creation and implementation of many different Ambient Information Systems are well documented there are still areas in the domain that require further investigation. This includes the difficult question of how best to evaluate Ambient Displays that may have both an aesthetic and informative function. Further work also needs to be done in categorising the key design features of the many different approaches used for Ambient Display. Furthermore, the use of 3D graphics to visualise information in the periphery has yet to be explored in any detail. This is in relation to the technical capability of rendering 3D graphics for real-time display and also in evaluating their utility. These various areas represent a gap in the domain knowledge related to Ambient Information Systems and each is addressed in this thesis.

In analysing the literature around Ambient Information Systems it is evident that there have been many attempts at developing Ambient Displays but less research that includes the evaluation of such displays. This domain knowledge gap is also identified directly in the literature, where a key issue surrounding evaluation methods is the lack of knowledge around what makes one Ambient Information System more effective in presenting peripheral information than another (Mankoff et al., 2003). Indeed, few evaluations have been performed on Ambient Information Systems (Skog, Ljungblad & Holmquist, 2003), displaying the lack of a universal evaluation method that can be applied to such displays in order to evaluate their effectiveness. Moreover, there are few implementations of Ambient Information Systems that have not been solely performed in a research setting (Nesbitt & Shen, 2007). Thus research opportunities exist in relation to the more formal evaluation of Ambient Information Systems and thus a significant contribution of this research project is the outcomes from an the intrusive in-situ evaluation of the WaveWatch display.

Ambient Information Systems have utilised a number of different types of Ambient Media to visualise information. Ambient Media is exemplified as the use of "sound, light, airflow, and water movement for background interfaces with cyberspace at the periphery of human perception" (Ishii & Ullmer, 1997). These various types of Ambient Media are well represented in the literature. For example, through displays such as *Pinwheels* (Wisneski et al., 1998) that utilises movement for information transmission, *Follow the Lights* (Rogers, Hazlewood, Marshall, Dalton & Hertrich, 2010) that uses light for its Ambient Media and *The Information Percolator* (Heiner, Hudson & Tanaka, 1999) that uses the movement of bubbles in water for displaying information.

In addition to the Ambient Information Systems that utilise physical objects for information transmission, there are a number of displays that utilise traditional 2D graphics on an LCD screen to display information. These 2D graphics often adopt the use of symbols or metaphors as a way to represent the underlying data. For example, the *Butterfly/Dragonfly* display (Nesbitt and Shen, 2007) uses 2D graphics on an LCD screen to display information, where the placement of a sequence of butterfly and dragonfly symbols are used to visualise information about stock prices over the last five days.

The use of 2D computer-generated graphics is a common approach when an LCD screen is used as the output mechanism for an Ambient Display. By contrast the use of 3D visualization is sparse when compared to this more typical use of 2D visual representation on a computer screen. For this reason, the second major aspect of this research examines the technical requirements and the general utility associated with the use of 3D graphics for data visualisation on an Ambient Information System. In addition to this novel use of 3D graphics, the feasibility of using an ocean wave metaphor for information transmission is also investigated.

Overall this thesis aims to investigate the domain of Ambient Information Systems through the development and evaluation of a novel Ambient Display that utilises 3D graphics and an ocean wave metaphor for information transmission. The design and implementation of this Ambient Display has been motivated by the current lack of domain knowledge around the evaluation of such displays, the absence of displays that utilise advanced 3D graphics for peripheral data visualisation and the exploration of an ocean metaphor for the visualisation of real-time data. A brief overview of the research (Section 1.3) and research methods (section 1.4) utilised in this project are discussed in the following sections.

1.3 – Purpose of the Research

This research aims to investigate a number of areas that currently require further investigation in the domain of Ambient Information Systems. The various aims of this research were integrated into a single research question:

> *What is the feasibility and effectiveness of developing an Ambient Information System that uses a 3D wave metaphor for displaying real-time web traffic data?*

Specifically, the research investigates the feasibility and effectiveness of a novel ocean wave metaphor for visualizing real time information, the use of 3D graphics on an Ambient Information System and the evaluation of an Ambient Display through an intrusive in-situ evaluation method.

1.4 – Research Design and Methodologies

A combination of a Case Study research design (Stake, 1995) and a Self-Completion Survey method (Bryman & Bell, 2011) were used to investigate the research question. Specifically, the research methodology is comprised of two parts:

1. The implementation of an Ambient Information System into an in-situ environment to assess the technical, design, development and deployment issues of implementing such a display and;
2. A Self-Completion Survey designed for evaluating the user experience and overall efficacy of the actual display's approach.

The Self-Completion Questionnaire was administered in the form of an online survey. The survey questions (see Appendix A) were developed from two previously documented technology evaluation methods. The first approach, based on Heuristic evaluation was specifically developed for the evaluation of Ambient Information Systems (Mankoff et al., 2003). This approach was combined with another more generic system evaluation method, the Usefulness and Ease of Use survey (Davis, 1989). The utility of both of these evaluation methods are explored in relation to the evaluation of an Ambient Information System.

The WaveWatch Ambient Information System was developed as a case study to address the research question of this thesis. Firstly, the creation of the WaveWatch facilitated the assessment of the technical feasibly to build such a display. Secondly an in-situ intrusive evaluation of the WaveWatch was performed to accesses the effectiveness of the display and its novel mode of visualisation in a real world scenario.

The WaveWatch was implemented into the Marketing and Public Relations (M&PR) office at The University of Newcastle, Australia. The WaveWatch was made to visualise the number of active users on a popular webpage on The University of Newcastle's website, which is managed by the M&PR team. WaveWatch was made to compliment the current web traffic reporting activates undertaken by the M&PR team by raising the awareness of web traffic volumes and patterns through the provision of web traffic data in the periphery.

1.5 – Summary

The research included in this thesis represents a significant contribution to the domain of Ambient Information Systems. A new type of design pattern, the *Aesthetic Awareness Display* is defined and explored through the WaveWatch case study. The research also investigates a novel form of Ambient Media using pre-rendered 3D graphics to animate the display. The research also reports on both the feasibility and effectiveness of a novel 3D visual representation, namely an ocean metaphor for representing real time dynamic data, such as web traffic. Finally the research also extends existing knowledge in relation to the in-situ evaluation of such displays.

This thesis includes a total of six chapters. Following chapter one, chapter two is comprised of a detailed synthesis of current domain knowledge through a literature review. Chapter three describes the research methods utilised by this research, chapter four describes the creation of the WaveWatch, chapter 5 details the results of the evaluation of the WaveWatch and chapter 6 concludes the thesis through a summation of the research findings as well as a discussion of possible future work.

In summary this thesis aims to investigate the feasibility and effectiveness of an Ambient Information System that uses a novel ocean wave metaphor for displaying real-time web traffic data. Specifically, the research investigates:

1. The feasibility and effectiveness of a novel ocean wave metaphor for visualizing real time information;
2. The use of 3D graphics for a real-time Ambient Information System and;
3. The efficacy of the Ambient Display as assessed through an intrusive in-situ evaluation.

All of these areas of the research were formulated through the observation of gaps in the domain of Ambient Information Systems that require further research and development. The focus of the research was also informed through the proposed *Aesthetic Awareness Display* design pattern, which is an extension to a current taxonomy of Ambient Information Systems (Pousman & Stasko, 2006). The creation of this new design type was established though a synthesis of current domain knowledge, which is discussed in chapter two.

Chapter 2

A Review of Ambient Information Systems

2.1 Introduction

In our everyday life we constantly receive ambient information from our environment. This occurs through a range of mediums such as sound, light, temperature and air movement. For example, we can receive information such as the time of day through the amount of light shinning through a window, the time to wake up in the morning from birds tweeting, the running condition of an air conditioner by the quality of sound it emits or even the degree of excitement at a party from the chaotic din of background noise.

These “natural” ambient information sources generally sit in the periphery of an individual’s attention. However, it also possible for a person to redirect attention to such peripheral information sources and thus focus more carefully on their content. This phenomenon is well known in visual information processing where the majority of the visual scene resides at the periphery of attention providing context to a much smaller focus of attention (Furnas, 1986). Uninteresting information sources such as a tree branch brushing against a window pane can be overlooked by an individual in preference for their primary information source. However, attention can swiftly be directed to an alternative location if startling stimuli, such as sudden unexpected motion or rapid changes in light alert the individual to potentially valuable information in the periphery (Sekuler & Blake, 1994).

The “Cocktail Party Effect” (Pollack & Pickett, 1957) illustrates a similar phenomenon of selective attention in the auditory domain. This effect uses the analogy of a cocktail party, to highlight the ability of an individual to focus their listening attention on a single conversational source in a crowd of conversations (Pollack & Pickett, 1957). For example, a background conversation where the individuals name is suddenly used.

While these ambient information sources are an abundant part of our natural environment they are less prevalent in our technological environments. Rather than sitting calmly in the periphery, traditional digital devices such as mobile phones, pagers and web browsers have been described as the enemy of calm (Weiser & Brown, 1996). This is due to their ability to demand immediate attention from the user. Opposed to these interrupting information devices is the concept of *Calm Technology* (Weiser & Brown, 1996) that aims to deliver information by devices in an individual's periphery. A carefully designed, "calm" or non-alerting display situated in ones periphery, can provide a user with information in a similar way to natural ambient displays. Such digital devices that deliver information while residing in an individual's periphery are often referred to as *Ambient Information Systems* or *Ambient Displays*.

A typical definition of Ambient Displays is:

"Ambient displays are abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user's attention." (Mankoff et al., 2003).

Since there is no uniformly accepted definition of Ambient Information Systems, the first role of this review is to highlight and compare the key features of Ambient Displays provided by various definitions (section 2.2). This is followed by a brief review of the different design motivations put forward for developing these systems (section 2.3). In both of these sections a number of examples of different Ambient Information Systems will be discussed.

One common attribute of Ambient Information Systems that emerges is that the information being provided is somehow relevant, but non-essential, or non-critical to the user's primary needs. The general notion of providing less critical ambient information in the environment through the use of various digital media is also part of the emerging trend of *Ubiquitous* or *Pervasive Computing,* where computers are beginning to exist everywhere and anywhere in our daily lives. This field and others inform the discussion of Ambient Information Systems. Therefore, a further role of this literature review is to provide the background context of the different technologies and fields of study that underlie the development of Ambient Information Systems (section 2.4). This will include a discussion of significant fields such as *Ubiquitous Computing, Information Visualisation and Calm Computing.* It will also include a discussion of the more niche domains of *Tangible User Interfaces,* *Informative Art* and *Information Decoration.* Once again, in this section numerous examples of Ambient Information Systems will be used to inform the discussion.

The result of comparing definitions for these systems, looking at the various business motivations, the individual characteristics of previous displays and the similar but disjoint fields of study that inform their design raises the question of how to best categorise the key types of Ambient Information Systems (section 2.5). This section will discuss proposed taxonomies and their key design dimensions and how they relate to our own study.

The disjoint design dimensions proposed by the various taxonomies raises some difficult issues around evaluating the usability and efficacy of such displays. For example, just what should be evaluated and how intrusive such evaluations can be. Unfortunately many previous Ambient Displays are lacking in formal evaluation. Even where evaluation has occurred the most relevant evaluation criteria and how to best perform the evaluation itself remain issues for discussion. The various approaches for evaluating Ambient Information Systems is the final area addressed by this literature review (section 2.6).

2.2 Defining Ambient Information Systems

Many different displays have been developed since 1996 (Weiser & Brown, 1996) that can be categorised as an Ambient Information System. These systems include, Informative Art (Redstrom, 2000), Digital Family Portraits (Mynatt, Rowan, Craighill & Jacobs, 2001), Ambient Mirrors (Nakajima & Lehdonvirta, 2011), Tangible Bits (Ishii & Ullmer, 1997), invisible displays (Offenhuber, 2008) or virtual paintings (Skog, Ljungblad & Holmquist, 2003).

An early example of an Ambient Information System was called Water Ripples (Ishii et al., 1998). Water Ripples reflected the shadows of moving water on the ceiling above the user. The ripples of the water were controlled by the activities of a hamster, if the hamster ran in its wheel the water ripples on the roof would vibrate. The Water Ripples display was implemented in an Ambient Information System known as the ambientROOM (Ishii et al., 1998). The ambientROOM was designed to allow for the design of various ambient information displays by supporting a range of novel ambient mediums such as light, sound, motion and airflow.

Another early Ambient Information System that used water to convey information was The Information Percolator (Heiner, Hudson & Tanaka, 1999). The Information Percolator (see figure

2.1) is comprised of a series of plastic tubes filled with water. Bubbles are injected into the water to represent data. One of the applications created for the display aimed to visualise the movement of individual's through a hallway. When a camera detected an individual this movement was mapped onto the Information Percolator by way of a spray of bubbles through the device's tubes.

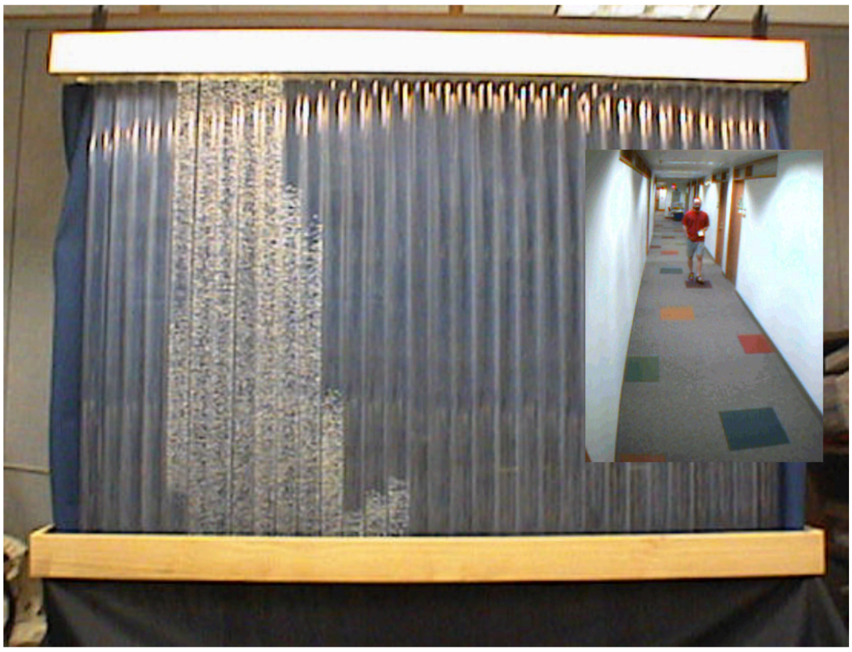


Figure 2.1 The Information Percolator visualising the movements of an individual through a hallway. Source (Heiner, Hudson & Tanaka, 1999).

Another example of an early Ambient Information System was the Informative Art display that was used to visualise bus departures in real time (Skog, Ljungblad & Holmquist, 2003). The display's design was inspired by the art of Mondrian and mapped the movements of buses by manipulating a piece of art on an LCD screen. Each coloured square that made up the display represented a bus. The size of each square would change in real time to represent the amount of time before a bus would leave a particular bus stop. It was installed in a university cafe where students might be interested in the arrival and departure of the buses being displayed.

Like the Mondrian Bus display the InfoCanvas was an Ambient Information System that utilised an LCD screen to deliver a visualisation to the user. In the case of the InfoCanvas a user could create a custom scene that could be mapped to a range of data sources (Stasko, Miller, Pousman, Plaue & Ullah, 2004). The user could choose a range of two-dimensional scenes to act as aesthetic base for the display. A series of abstract items could then be added to the display, which could be used to symbolically present the underlying data. For example, the position of an airplane in the sky could represent the current temperature or the number of cups on a beach could represent a current stock price.

The Digital Family Portrait, another prominent display from the literature (Mynatt, Rowan, Craighill & Jacobs, 2001) took the form of a photo frame that was also capable of delivering information to the user. The aim of the project was to create a device that could help the family members of an elderly individual become more aware of their elderly relatives activates, health and well being. Information about the elderly individual was visualised through a series of icons on the frame that were used to represent a range of metrics relating the individuals well being. The display was primarily intended to relay information to a family about the activity of a distant elderly relative.

These previous examples help to highlight some key features captured in various definitions.
Most commonly the term "Ambient Display" has been used to describe these systems and various definitions such as the three below have been suggested.

"ubiquitous computing devices which monitor and display information in a peripheral, non-obtrusive way, and are meant to reduce demand on one's memory and overloaded senses" (Ames & Dey, 2002)

"Ambient displays are abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user's attention." (Mankoff et al., 2003)

"An ambient display resides in the periphery of a person's attention. The display calmly changes state in some way to reflect changes in the underlying information it is representing" (Stasko, Miller, Pousman, Plaue & Ullah, 2004)

"Informative Art" is perhaps a more specific type of Ambient Display as it focuses more specifically on the aesthetic qualities of the display and has been defined as:

"computer augmented, or amplified, works of art that not only are aesthetical objects but also information displays, in as much as they dynamically reflect information about their environment" (Redstrom, 2000).

Analysing these various definitions highlights that such displays focus on displaying information in the periphery though novel means with an additional concern for producing an aesthetically pleasing display.

These previous examples also demonstrate the diversity of such displays, a diversity that lends itself to further consideration. In the next sections we look more closely at some of the clear distinctions that occur between these diverse Ambient Displays. This includes a look at the different physical forms of display (section 2.2.1), the various levels of ambience designed into such displays (section 2.2.2).

2.2.1 Tangible versus screen-based displays

The designs of Ambient Information Systems often differ from one another in relation to a number of physical design features. Most notable of these design considerations is the physical form of the display itself, where two opposite trends have developed around the use of either tangible-object based displays or more traditional screen based displays. The trends surrounding both of these design types are discussed in this section.

Tangible Ambient Information Systems are displays that utilise ambient objects that are physical in order to deliver information to the user. Often such displays are also referred to as Sculptural Displays (Pousman & Stasko, 2006). There are many examples throughout the literature of physical objects that have been used as Ambient Information Systems, but Ishii's research into Tangible User Interfaces account for many of the early examples (Ishii & Ullmer, 1997). One good example, commonly referred to as the Dangling String (Weiser & Brown, 1996) or Live Wire has been cited as being the root of all Ambient Displays (Messeter & Molenaar, 2012). Dangling String was an Ambient Information System created by artist Natalie Jeremijenko. It comprised an eight-foot piece of plastic "spaghetti" that hung from the celling (Weiser & Brown, 1996). The display, which used the physical medium of a moving string as well as the sound it emitted, was used to notify individuals of network traffic. A more excited wire indicated more traffic on the network. It was the Dangling String display that was cited by Weiser & Brown to demonstrate the concept of Calm Computing (Weiser & Brown, 1996).

Throughout the literature there are also a large number of displays that can be grouped by their common use of LCD screen technology to deliver information. While the use of an LCD display may seem contradictory to the concepts of Calm Computing, many of the displays that utilise an LCD display identity as being Ambient Art (Redström, Skog & Hallnäs, 2000). Such art displays can sit calmly in their environments as wall art is often integrated into ones environment (Redström, Skog & Hallnäs, 2000). Ambient Art is well suited to the use of LCD displays for information transmission due to the concept's focus on mapping layers of information onto pieces of art, typically pictures or posters (Redström, Skog & Hallnäs, 2000).

One such example that demonstrates the typical attributes of a screen based display but is also considered a piece of Ambient Art is the Butterfly/Dragonfly display (Nesbitt & Shen, 2007). Butterfly/Dragonfly is an Ambient Information system that displays Australian Stock Exchange data in the periphery through the metaphor of Ambient Art. The display utilises the placement of a sequence of butterfly and dragonfly symbols in order to visualise information about stock prices over the last five days. The display is made ambient to the environment by placing the monitor in a typical art-like frame. The style of the artwork is consistent with other paintings in the office where it was located. Due to the commonality of wall art in the home and work environments, this pragmatic approach helps to make such displays ubiquitous and configurable to a range of environments.

Through viewing both the sculptural Ambient Information Systems and the screen based Ambient Information Systems in the literature it is evident that screen based displays do hold advantages over their sculptural/tangible counterparts, namely in their ability to map multiple information sources onto a single peripheral display. This flexibility and also the fact that they adapt existing display technology is possibly the reason as to why they are prevalent in the literature.

Sculptural Displays usually only feature a single piece of information (Pousman & Stasko, 2006), this is evident in the literature where systems such as "Show-me" (Kappel & Grechenig, 2009) and The Power-aware Cord (Gustafsson & Gyllenswärd, 2005) only display a single metric. In the case of "Show-Me", real-time water usage is presented to the user through a series of LED lights. The Power-aware cord displays the power consumption of a particular appliance through a glowing cord. Both The Power-aware cord and Show-Me aim to increase the awareness of a single metric to the user though means of tangible changes to an object.

While both of the aforementioned displays are built to display a single metric to a user, screen based displays can visualise a number of metrics from many sources. One such example of a screen based display that conveys multiple metrics to a user through a screen based Ambient Information System is the MoneyTree (Eades & Shen, 2004). MoneyTree delivers real time information about both changing stock prices and volumes on a screen based display that uses a growing tree metaphor. This novel metaphor also illustrates the range of data mappings that can be accomplished when choosing a screen-based display.

2.2.2 Levels of Ambience

In terms of interaction there are many displays within the literature that require no direct input from the user in order to function or be useful. These displays represent the purest form of Ambient Information Systems in that they act solely as a peripheral device to output information. We might describe these as fully-ambient systems (see Table 2.1 for examples). The purposeful lack of interaction embodies the concepts of Calm Computing. By contrast a device that requires too much interaction from the user threatens to become the "enemy of calm" (Weiser & Brown, 1997). This is critically important if we imagine a future where such displays may become pervasive.

Exemplifying the concepts of a fully Ambient Information System that requires no interaction in order to fully operate is the Mondrian bus display (Skog, Ljungblad & Holmquist, 2003). The display can be classified as being fully ambient due to the fact that no direct input interaction is required from the user to utilise the display, in that it can be utilised simply by glancing at it within it's public environment.

The other trend emerging around interaction and Ambient Information Systems is related to the displays that might be described as semi-ambient. These displays differ to their fully ambient counterparts, while they do deliver information through the periphery they require direct purposeful input from the user to fully function, or become more useful when such interaction occurs.

Table 2.1 Fully Ambient Information Systems from the literature

Display Name	Year	Authors
AmbientROOM	1997	(Ishii & Ullmer, 1997)
The Water Lamp	1998	(Wisneski et al., 1998)
Pinwheels	1998	(Wisneski et al., 1998)
The Information Percolator	1999	(Heiner, Hudson & Tanaka, 1999)
Informative Art	2000	(Redström, Skog & Hallnäs, 2000)
InfoCanvas	2001	(Miller & Stasko, 2001)
The Digital Family Portrait	2001	(Mynatt, Rowan, Craighill & Jacobs, 2001)
Mondrian bus display	2003	Skog, Ljungblad & Holmquist, 2003
MoneyTree	2004	(Eades & Shen, 2004)
The Power-Aware Cord	2005	(Gustafsson & Gyllenswärd, 2005)
BreakAway	2005	(Jafarinaimi, Forlizzi, Hurst & Zimmerman, 2005)
PlantDisplay	2006	(Kuribayashi & Wakita, 2006)
AmbientLamp	2007	(Lee, Cho, Park & Hahn, 2007)
Shopping Display	2007	(Reitberger, Obermair, Ploderer, Meschtscherjakov & Tscheligi, 2007)
The Ambient Calendar	2008	(Phelan, Coyle, Stevenson & Neely, 2008)
Flowers or Robot Army	2008	(Consolvo et al., 2008)
InfoPulse	2008	(Migicovsky, 2008)
Show-me	2009	(Kappel & Grechenig, 2009)
Ambient Rabbits	2009	(Mirlacher, Buchner, Förster, Weiss & Tscheligi, 2009)
ResearchWave	2010	(Hinrichs, Fisher & Riche, 2010)
Follow the lights	2010	(Rogers, Hazlewood, Marshall, Dalton & Hertrich, 2010)
AmbientNEWS	2010	(Valkanova, Moghnieh, Arroyo & Blat, 2010)
Time Management Display	2011	(Occhialini, van Essen & Eggen, 2011)
MoveLamp	2013	(Fortmann, Stratmann, Boll, Poppinga & Heuten, 2013)

One example of a display from the literature that is identified as being semi-ambient is the LumiTouch display (Chang, Resner, Koerner, Wang & Ishii, 2001). While having typical elements of an Ambient Information Systems in that it does deliver information in an aesthetic manner through the periphery, the LumiTouch differs in that it also incorporates direct user interaction.

The LumiTouch is a communication device in the form of a photo frame the can be used to communicate with another individual who has a LumiTouch Display. The LumiTouch incorporates interaction through a series of touch sensors along the front of the frame that can be pressed by the user. Such touch interactions are communicated to the other paired LumiTouch display to create communication between two individuals. While there are other possible methods of communication through the LumiTouch that do not require such direct interaction, it is clear that during such an interaction with the touch sensor that the device is no longer ambient or in the user's periphery for an extended period of time. This purposeful removal of the display from the periphery to centre of a user's attention in order to complete an input differentiates such a display from a fully ambient display.

Through analysing the displays that have been reported in the literature, it is evident that fully Ambient Information Systems are more common than semi-ambient Information systems. Furthermore, it suggests that some consideration for ambience or interaction level needs to be a design parameter considered when developing such displays.

Table 2.2 Semi-Ambient Information Systems from the literature

Display	Year	Authors
LumiTouch	2001	(Chang, Resner, Koerner, Wang & Ishii, 2001)
Hello.Wall	2003	(Prante et al., 2003)
CareNet Display	2004	(Consolvo, Roessler & Shelton, 2004)
Nimio	2005	(Brewer, Williams & Dourish, 2005)
PhantomParasol	2006	(Tsukada & Masui, 2006)
TeaPlace	2007	(Lee, Cho, Park & Hahn, 2007)
Ambient Mirrors	2013	(Nakajima & Lehdonvirta, 2013)

2.2.3 Summary

In reviewing the key features and definitions of Ambient Information Systems it is evident that such displays can be differentiated by physical form (tangible or screen based), and further differentiated by levels of interaction or ambience. However, through analysing the displays in the literature it is also evident that there is no clear and consistent definition of Ambient Displays or the key design features that constitute them. In the next section we will consider the various motivations or business cases that are put forward for developing such displays.

2.3 Motivations for Developing Ambient Information Systems

When analysing the Ambient Information Systems described in the literature there are some common motivations for creating such a display that can be identified. These common motivations are most often related to increasing information awareness, communicating and encouraging behaviour change. There are also some displays that have no particular, underlying business motivation. In this section we describe each of these motivation categories and classify previous displays into four motivation groups.

2.3.1 Increasing Information Awareness

A subset of displays within the literature can be characterised through their collective aim to raise awareness of a particular data metric or set of metrics. Typical information presented on Ambient Information Systems that do aim to increase information awareness includes information regarding the wellbeing of family members (Mynatt, Rowan, Craighill & Jacobs, 2001), weather information (Mirlacher, Buchner, Förster, Weiss & Tscheligi, 2009) and stock market information (Nesbitt & Shen, 2007). Such displays are designed to inform a user of information that they would not otherwise be aware of (see table 2.3 for more examples).

One such display that exemplifies an Ambient Information System that is used for awareness purposes is the CareNet Display (Consolvo, Roessler & Shelton, 2004). The CareNet Display is a semi-Ambient Information System in the form of a photo frame. The CareNet presents information about the daily activities of an elderly individual in order to increase awareness of their activities to a caregiver. A similar solution for increasing awareness of an elder’s activities is seen in The Digital Family Portrait (Mynatt, Rowan, Craighill & Jacobs, 2001).

Table 2.3 Examples of Ambient Displays designed to Increase Information Awareness

Display	Year	Authors
AmbientROOM	1998	(Ishii et al., 1998)
The Information Percolator	1999	(Heiner, Hudson & Tanaka, 1999)
The Digital Family Portrait	2001	(Mynatt, Rowan, Craighill & Jacobs, 2001)
MoneyTree	2004	(Eades & Shen, 2004)
The CareNet Display	2004	(Consolvo, Roessler & Shelton, 2004)
The Power-Aware Cord	2005	(Gustafsson & Gyllenswärd, 2005)
Butterfly/Dragonfly	2007	(Nesbitt & Shen, 2007)
Ambient Shopping display	2007	(Reitberger, Obermair, Ploderer, Meschtscherjakov & Tscheligi, 2007)
PlantDisplay	2007	(Lee, Cho, Park & Hahn, 2007)

InfoPulse	2008	(Migicovsky, 2008)
The Ambient Calendar	2008	(Phelan, Coyle, Stevenson & Neely, 2008)
Ambient Rabbits	2009	(Mirlacher, Buchner, Förster, Weiss & Tscheligi, 2009)
AmbientNEWS	2010	(Valkanova, Moghnieh, Arroyo & Blat, 2010)
ResearchWave	2010	(Hinrichs, Fisher & Riche, 2010)
Meeting Time management Display	2011	(Occhialini, van Essen & Eggen, 2011)

2.3.2 Encouraging Behaviour Change

In this section we consider examples in the literature that aim to encourage changes in behaviour. It could be argued that these Ambient Information Systems also aim to increase awareness of a particular metric or set of metrics. However, the displays described in this section describe a clear motivation of their intention to display information to the user thorough the periphery and also to encourage specific behavioural patterns. Ambient information systems that aim to change a user's behaviour typically state such motivations explicitly to the user as well as the source of the data so they are aware that the display is encouraging a particular shift in behaviour (Rogers, Hazlewood, Marshall, Dalton & Hertrich, 2010).

Ambient Information Systems that aim to change a user's behaviour typically display information about resource use, exercise patterns or other use behaviours, with the aim to inspire a change through providing peripheral feedback that otherwise would be totally invisible or at least not available in real time (see Table 2.4 for more examples). Exemplifying this type of Ambient Information System is the MoveLamp (Fortmann, Stratmann, Boll, Poppinga & Heuten, 2013). The MoveLamp aims to motivate office workers to take more steps throughout the day then they typically would without having the display installed. The device itself is a sculptural Ambient Information System in the form of a lamp that changes colour depending on the number of steps taken by the user. A battery metaphor is utilised by the display to indicate activity, where a bright green light indicates that step activity is sufficient and a dark red light indicates that the user has not been walking enough. An evaluation of the MoveLamp was conducted where it was discovered that the walking frequency of ten participants was increased after the implementation of the display, demonstrating the potential for Ambient Information Systems to not only inform but to also motivate users to change their behaviour.

Table 2.4 Ambient Information Systems that encourage behavioural change

Display	Year	Reference
Breakaway	2005	(Jafarinaimi, Forlizzi, Hurst & Zimmerman, 2005)
UbiFit	2008	(Consolvo et al., 2008)
Ambient Display as a Persuasive Medium for Exercise Awareness	2008	(Fujinami & Riekki, 2008)
Show-me	2009	(Kappel & Grechenig, 2009)
Twinkly Lights	2010	(Rogers, Hazlewood, Marshall, Dalton & Hertrich, 2010)
Ambient Mirrors	2013	(Nakajima & Lehdonvirta, 2013)

2.3.3 Communication

Another apparent trend in the literature are Ambient Information Systems geared towards communication. Such displays often include sensing hardware or interactive interfaces that help support two-way communication, and might be better described as semi-ambient rather than fully ambient displays.

The LumiTouch (Chang, Resner, Koerner, Wang & Ishii, 2001), described as an emotional communication device is a representative example of this form of Ambient Information System. The LumiTouch is an interactive picture frame that creates subtle levels of communication between users. Two frames are paired where if a user is in front of one of the frames the corresponding frame glows indicating their presence. The LumiTouch is unique as although it is an ambient device it does have interactive elements through its sensing hardware indicating that the display sits somewhere in-between traditional Ambient Information Systems and Direct commination devices (Chang, Resner, Koerner, Wang & Ishii, 2001).

Unlike the sculptural LumiTouch, the “Celling as an Ambient Display” (Tomitsch, Grechenig & Mayrhofer, 2007) is a projected visual display, although like LumiTouch it has been designed to promote communication. Using the ceiling as a surface to projection on, patterns of light represent the emotions of a second user who has their own ambient ceiling display. Each user conveys their emotions through manipulating a tangible cube, once again indicating that communication oriented Ambient Information Systems do rely on a certain level of interaction from the user.

2.3.4 Non-business related

It is clear that Ambient Information Systems falling under each of the previously defined categories do have a purpose that often solves an issue or provides some business case to motivate their development. However, this is not always the case when examining the motivations of some Ambient Information Systems. A small subset of displays do not set out to solve a set business case, address a specific problem, change a users behaviour or inform them of a specific metric.

The Tea Place (Lee, Cho, Park & Hahn, 2007) is a novel ambient display that does not fit into any of the three common motivation categories previously discussed. This display aims to provide the user with a visual and auditory experience dependent on the colour of tea that they are drinking. Once a user places their cup of tea on a table, sensing technology determines the colour of their beverage and displays patterns of light and calming sounds depending on the colour. The Tea Place does take a departure from the more common displays in the literature that aim to provide useful information to the user. This departure from the more common paradigms does reveal that Ambient information Systems don't have to strictly aim to promote awareness, encourage behaviour change or be a communication device, although each of those categories are far more common throughout the literature in comparison to non-business related Ambient Information Systems such as the Tea Place.

2.4 Technologies Influencing Ambient Information Systems

From examining the literature related to Ambient Information Systems it is apparent that this field of study is enabled by a combination of key technologies and principles that have been influenced by work in many related fields of study. In this section we review these major influences and their relationship to Ambient Displays in an effort to provide more context to this research (see figure 2.2). This review includes a discussion on the relevance of established fields such as User Interface Design, Information Visualisation and Human Computer Interaction. It also discusses emerging concepts such as; Ubiquitous computing (Occhialini, van Essen & Eggen, 2011) (section 2.4.1); Calm Technology (Weiser & Brown, 1997) (section 2.4.2), Information Decoration (Eggen & Van Mensvoort, 2009), Ambient Media (Ishii & Ullmer, 1997) and Tangible User Interfaces (Ishii & Ullmer, 1997).

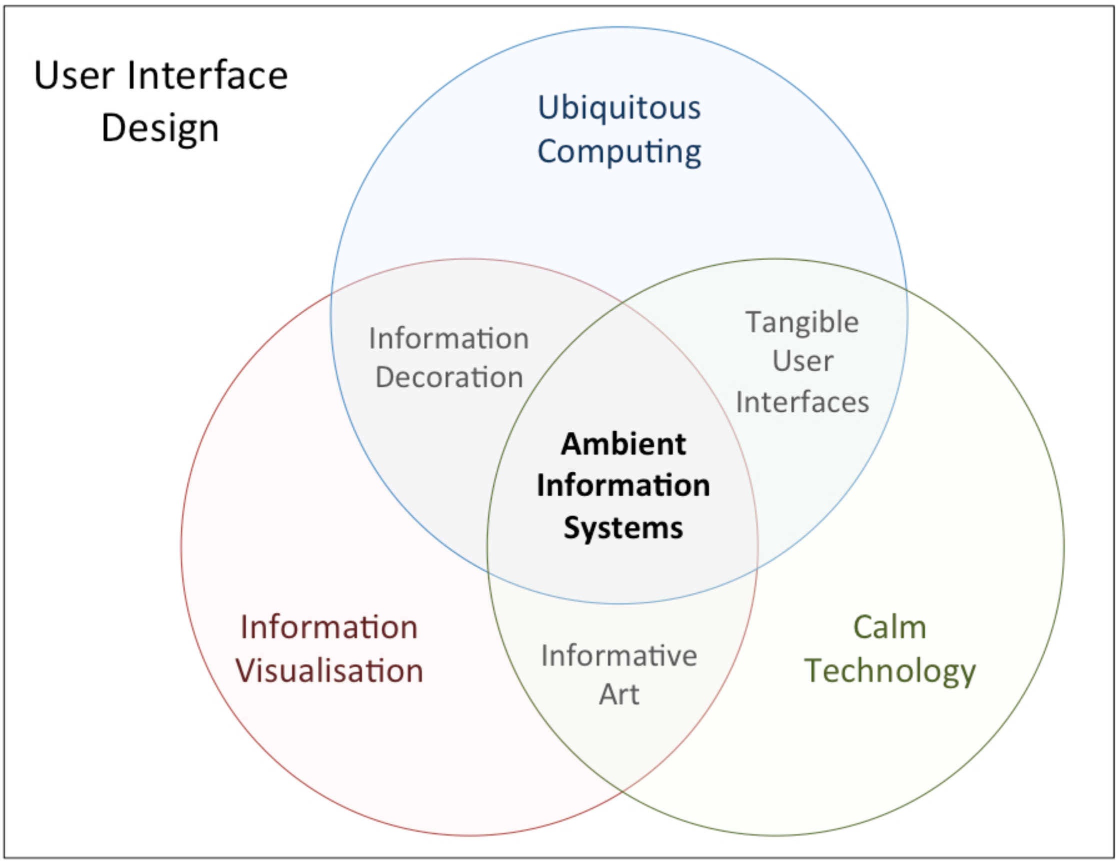


Figure 2.2 - Ambient Information Systems have developed through a convergence of related technologies, including Ubiquitous Computing, Calm Technology and Information Visualisation. It is a specialised area of user interface design.

2.4.1 Ubiquitous Computing

The term Ubiquitous Computing was coined by Mark Weiser (Weiser, 1991) as a vision of the "Computer for the 21st Century". The concept of Ubiquitous Computing, also known as Pervasive Computing, predicts the possibility that computers, in one guise or another, will be universally available in the day-to-day environment. Thus computers of all types will be connected to create intelligent objects and environments that will exist everywhere and anywhere.

Ambient Information systems form part of this Ubiquitous Computing world, as digital information displays populate not only our current field of focus but also our periphery. For example buildings themselves may become displays that provide constant updates of information. Weiser describes the most "profound technologies", as "those that disappear. They in fact weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser, 1991).

The first example of an Ambient Information System, the "Dangling String" (Weiser & Brown, 1996) illustrates some of the key features of both Ambient Information Systems and Ubiquitous

Computing. The “Dangling String” was designed to deliver information about the amount of network traffic passing through an Ethernet cable (Weiser & Brown, 1996). The Dangling String focuses on presenting information in the periphery and addresses the need for considering the aesthetics of the display. This exemplifies Weiser’s idea that Ubiquitous technologies should disappear or be indistinguishable from their everyday environment and integrated seamlessly into ones life (Weiser, 1991).

Ambient Information Systems also attempt to integrate into the background environment to deliver information through the periphery (Nesbitt & Shen, 2007). The desire for Ambient Information Systems to meld with the background is further illustrated through related concepts such as Informative Art (Redström, Skog & Hallnäs, 2000) where effort is put into the displays aesthetics to make the technology more seamless in the environment and therefore less intrusive.

The research of Redström, Hallnäs and Holmquist exemplifies many of the first Ambient Information Systems that are considered as being Informative Art. Preceding the Mondrian styled Informative Art display from Mynatt, Rowan, Craighill & Jacobs (Mynatt, Rowan, Craighill & Jacobs, 2001) Redström introduced a Mondrian style Informative Art display that delivered information to the user about email traffic through modifying the aesthetics of an existing Mondrian piece of art (Redström, Skog & Hallnäs, 2000).

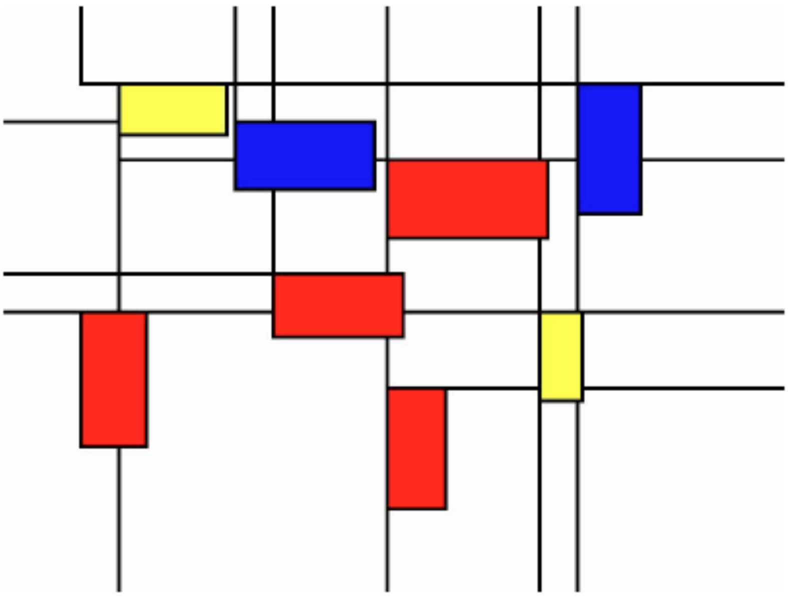


Figure 2.3 An informative art work based on the work by the artist Mondrian, designed to reflect information about email traffic. A similar display was used to show the movement of buses. Source: (Redstrom, et al., 2000).

Another example of an Informative Art display introduced by Hallnäs and Redström is a clock display inspired by Klein's monochromes (Hallnäs & Redström, 2001). The display coveys time to the user through geometrical shapes that change colour subtly to represent the passage of time. Another clock display that utilised the principles of Informative Art was the Soup Clock (Holmquist & Skog, 2003). Using a vastly different aesthetic model in comparison to the Klein's monochromes display (Hallnäs & Redström, 2001), the Soup Clock uses the Pop art of Andy Warhol to convey information. Acting as an egg timer the display uses the iconic Campbell's soup cans which change colour to represent the passing of time.

Another concept related to Weiser's vision of Ubiquitous Computing and Ambient Information Systems is the notion of Tangible Bits (Ishii & Ullmer, 1997). Tangible Bits describes a vision for Human Computer Interaction where computer information (or "Bits") is coupled with common physical objects. In demonstrating the concepts of Tangible Bits, Ishii & Ullmer present several early Ambient Information Systems including the ambientROOM (Ishii & Ullmer, 1997).

Other examples that illustrate the concept of Tangible Bits include Water Lamp and Pinwheels (Wisneski et al., 1998). Being standalone Ambient Displays, Water Lamp and Pinwheels are described by Dahley, Wisneski & Ishii as being Ambient Fixtures (Dahley, Wisneski & Ishii, 1998) due to their ability to be moved and distributed throughout open architectural space, allowing them to be viewed by several individuals at any one time (Dahley, Wisneski & Ishii, 1998).

The Water Lamp display takes the form of a water pan and three solenoids supported by aluminium tubes (Dahley, Wisneski & Ishii, 1998). When data is received, the solenoids tap the water pan to convey data to the user. Patterns of light are projected from the Water Lamp by a light bulb below the water pan projecting water ripples onto the ceiling (see figure 2.4). These water ripples provide visual indicators to the user signifying a change in the data being represented. The Pinwheels display was used to visualise wireless LAN traffic data (Dahley, Wisneski & Ishii, 1998). Taking the form of a series of Pinwheels, airflow was applied to the display to make the pinwheels spin in order to deliver information to the user (see figure 2.5)

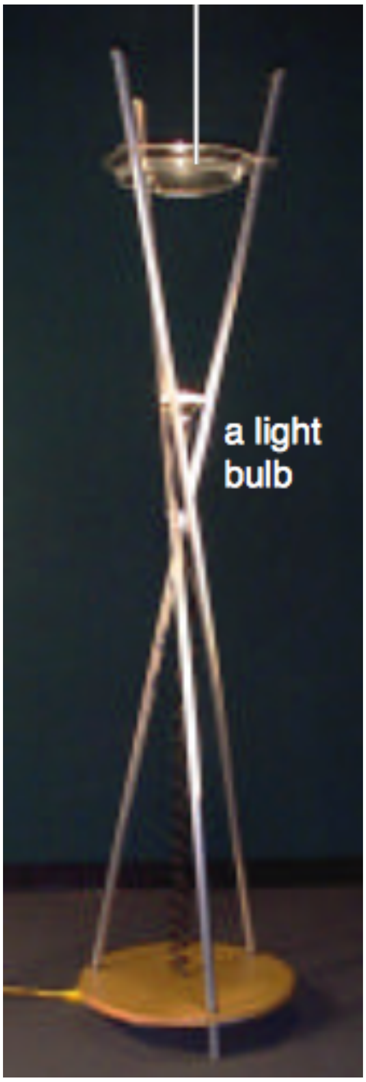


Figure 2.4 The Water Lamp Display. Source (Dahley, Wisneski & Ishii, 1998).

Figure 2.5 The Pinwheels Ambient Fixture. Source (Dahley, Wisneski & Ishii, 1998).

The concept of Tangible Bits is similar to that of Ubiquitous Computing in that it has a focus on computing technologies that reside within ones environment and are available in a way that allows them to move from a person's periphery to their primary focus. They essentially allow an interactive bridge between everyday objects, their environment and the underlying computing systems. Ambient Information Systems can also be considered to bridge the gap between the virtual and real world through such tangible objects that are augmented by digital information. Although, generally the focus of Ambient Information Systems is on the display (output) of information, rather than providing the two-way interactive mechanisms (input and output) that might be enabled when handling and manipulating tangible objects.

While the concept of Tangible Bits is related to Ubiquitous Computing the original descriptions of Ubiquitous technologies (Weiser, 1991), describes what is referred to as wearable tabs, hand-held pads and interactive boards which, while being tangible do still utilise a more traditional GUI-Style interface (Ishii & Ullmer, 1997). By contrast Ishii & Ullmer's implementation of Tangible Bits introduces everyday objects as interactive props that control the computer system through novel metaphors removed from traditional desktop interaction. Extensions to Weiser's tabs, pads and boards have been proposed that allow it to include these more novel types of interaction (Poslad, 2009). Suggestions include the idea of miniaturised smart *dust*, flexible display surfaces or *skin* and deformable 3D objects described to be more like digital *clay* (Poslad, 2009).

Like Tangible Bits and these novel interaction media, Ambient Information Systems typically focus on more abstract metaphors from the real world environment. While they often utilise traditional display devices seen in Graphical User Interfaces they tend to introduce more novel display metaphors and rely on aesthetics that depart from the typical usability goals that underpin traditional user interface design.

Despite some slight differences, it is evident that the pervading idea from Ubiquitous Computing and Tangible Bits, is that computer interfaces can become ubiquitous within ones environment and involve interaction with tangible objects. The aesthetics of everyday objects has helped to shape the principles of Ambient Information Systems.

2.4.2 Calm Technology

One potential issue with Ubiquitous Computing is the potential to generate high levels of background noise that will interrupt individuals focusing on specific tasks. Some argue that the alarming capabilities of such traditional computing devices, such as mobile telephones, pagers, email and the World-Wide-Web represent Information Technologies that are the "enemy" of calm (Weiser & Brown, 1997). This has led to the concept of Calm Technology (Weiser & Brown, 1997). Calm Technology differs from traditional computing paradigms in that it focuses on designing systems that support divided attention. That is, they can easily move forward from the user's background to become the centre of the attention and then fall back into the periphery again.

This ability for a technology to move between one's periphery and to the centre of their attention is also a defining feature of Ambient Information Systems. Such displays should be non-intrusive, sitting in the periphery of a user's attention but also have the capacity to be brought into focus when desired and then simply transitioned back to the user's periphery as needed. Thus Calm Technology concepts have also impacted on the development of Ambient Information Systems.

Weiser and Brown expand on their concept of Calm Technology by defining two typical indicators of a Calm Computing device (Weiser & Brown, 1997). The first, as previously explained is the power of Calm technologies to easily move form the periphery to the centre of ones attention. The second indicator of this technology is its ability to enhance our periphery by placing more details into it. Each of these defining characteristics of Calm Technologies are clearly evident in Ambient Information Systems.

A typical example of an Ambient Information System with both of these Calm Technology characteristics is the 'Breakaway" Ambient Display (Jafarinaimi, Forlizzi, Hurst & Zimmerman, 2005). Breakaway is a dynamic sculpture that sits on a desk and changes shape slowly to reflect different postural forms, such as a slouching or upright body posture. Its lifelike form responds to the amount of time a person has spent sitting at the desk and is intended to motivate positive changes in human behaviour by encouraging individuals to take appropriate work breaks.
The design goal for the "Breakaway" device was to create an abstract, non-intrusive and aesthetically pleasing display. These design goals in themselves address the main identifying factors of Calm Technologies where the intention is to make a non-intrusive device that easily slips into the user's periphery. This requirement for fitting into the background is further reinforced through making the device aesthetically pleasing. The notion of Calm Technology is reinforced in the way the

"Breakaway" changes state. It uses slow and graceful movements that will not alarm users. This allows the display to more easily remain in the user's periphery without generating a jarring, attention grabbing experience, each time it changes state. The second typical aspect of Calm Technology is also visible in the Breakaway display where further detail is added to the user's environment by means of a sculptural display that provides indirect feedback related to the user's sitting behaviour.

Observing these two main concepts of Calm Technology, namely, to provide additional background information and to use technologies that can move between the periphery and centre of ones attention it is clear that these themes are also reflected in the way Ambient Information Systems are designed.

Designing Ambient Displays, whether visual, auditory or tactile in nature also requires the understanding of how to map data into information. The principles and processes related to designing this data mapping is also a core theme that drives the well-established domain of Information Visualisation. This field of study and its relationship to Ambient Information Systems is discussed in the next section.

2.4.3 Information Visualisation

Information Visualisation is the term commonly used to describe interactive computer systems that provide the user with external visual models of abstract data. Thus, Information Visualisation is a field of study that concerns itself with the appropriate visual display of abstract data (Tufte, 1983; Card, Macinlay, et.al 1999; Nesbitt, 2003, Börner & Polley, 2014; Harris, 1999). Abstract data has by nature no physical relationship to the real world. The abstract data is taken from such domains as the stock market, network traffic, software engineering or marketing. These abstract domains often have no real-world model or analogue that can be used for structuring the information in a way that is intuitive to the user. Therefore, information visualisations typically employ abstract, mathematically-defined coordinate spaces for presenting information and also often adapts symbolic or more iconic metaphors in their design.

This contrasts with the notion of *Scientific Visualisation* where the focus is on the visual display of scientific and engineering data that has a direct physical basis in the real world. Scientific Visualisation usually adopt this physical-world structure or geometry on which they overlay the data. These structures are application dependent, but include typical models from the physical sciences such as geological, anatomical and mechanical structures. Overlaid on these structures is the data that may derive from physical simulations, geophysical surveys, weather modelling or collected medical diagnostics (Defanti, Brown, et al., 1989).

Cartography is a related area, where traditional maps have been extended to display information such as population data, economic indicators and health information that have a basis in the underlying geography. The principle of using maps to navigate physical spaces has been extended and adapted for the design of maps that help users navigate quite abstract "idea" or knowledge spaces (Börner, 2010).

Regardless, what all these fields have in common is the careful presentation of data in a way that allows users to better interpret the data and find useful patterns. In this sense they all have underlying principles that can be used to inform the design of visual, Ambient Information Systems.

The display of abstract data is a relatively recent event. For example, it was not until about 1750 that statistical graphics represented data by means of a time-series chart and scatterplots (Tufte, 1983). The early work by William Playfair in this area helped develop many fundamental visual designs for abstract data. Pie charts, bar charts, spider diagrams, line graphs are among the commonly used display forms (Tufte, 1983).

With the advent of computer technology it became possible to rapidly process larger data sets and produce more complex visual displays of the data. These included early novel display forms such as, Themescapes (Wise, Thomas et al. 1995), Treemaps (Johnson & Shneiderman, 1991), VisDB (Keim & Kriegel, 1994), Parallel Coordinates (Inselberg, 1997) and many early examples of network visualisation such as SeeNet (Eick and Wills, 1993), Narcissus (Hendley, Drew, et al. 1995), Hyberbolic trees (Lamping and Rao, 1994) and Cone Trees (Roberston, Mackinlay et al. 1991).

Some visual displays have adapted natural or environmental metaphors for display. These metaphors come from both the constructed world such as Cityscape (Russo Dos Santos et al. 2000), and the natural environment such as the Bid-Ask landscape (Nesbitt & Barass, 2002). The WaveWatch display described in this research, is based on the way waves break and is another example of adapting a naturally occurring metaphor.

Many guides to help design "good" visual displays already exist (Tufte, 1983; Tufte, 1990; Tufte 1997; Schneiderman, 1992; Nesbitt, 2001) and these sources can help inform the design of Ambient Displays.

In terms of other senses, *Information Sonfication* studies the auditory display of abstract data. Information Sonification is still an evolving field that uses sound rather than vision to represent abstract data (Kramer, 1994). The term, Information Sonification, implies a mapping from the data attributes to the sound parameters. In some earlier examples, sound has been used to assist in debugging software (Jameson, 1994), to display scatter plots (Madhayyastha and Reed, 1994) and to help understand parallel program performance (Jackson & Franconi, 1994) and to display computational fluid dynamics data (McCabe & Rangwalla, 1994).

In a further sensory domain, *Information Haptisation* looks at ways to display abstract data using the sense of touch (Nesbitt, 2002). *Information Perceptualisation* (Card, Mackinlay et al., 1999) or multi-sensory display (Nesbitt, 2003) is used to describe the reliance on many senses for displaying information. Work in this area is less complete and although attempts to better categorise the multi-sensory design space do exist (Nesbitt, 2005) there are no standard approaches for developing multi-sensory displays and design often involves trade-offs and iterative refinement of initial design decisions.

2.4.4 User Interface Design

Ubiquitous Computing, Calm Technology, and Information Visualisation usually involve some form of interaction, either input or output, between human and computer and in this sense they can all be discussed in terms of user-interface design. Human Computer Interaction (HCI) is the field of study that specialises in understanding the theoretical interaction between people and computers, while Usability Engineering is a more applied field of interface study. Both of these areas present some difficulty when studying Ambient Information Systems.

In terms of HCI, most studies rely on summative style assessment of interface technologies. However, this evaluation implies some way of measuring the user performance in relation to clearly defined user goals for the interface. It is common to evaluate user interfaces against design goals described by selected usability goals and user-experience criteria (see Table 2.5) and generally it is expected the interface to be studied has the primary focus of the user's attention. While traditional usability goals such as efficiency or utility can still be important for Ambient Information Systems, equally important are the ideas of ambience and their non-interrupting nature. Ambient Information

Systems also need to support a range of user-experience criteria so that such displays can be evaluated as helpful, motivating, fun and how they support creativity in terms of allowing users to find new patterns in the displayed data. Finally, more traditionally associated with art and design, is the requirement that some of these displays are aesthetically pleasing. The various approaches to evaluating these types of displays are discussed later in section 2.6. However, in summary, definitive, formal, objective evaluations of Ambient Displays have proved difficult to develop and perhaps this is why the Human Computer Interaction literature contains few evaluations of these displays.

An alternative, pragmatic approach to developing good interfaces is to adopt a user-centered design approach (Preece, Rogers and Sharp 2002). This approach can be supported by an iterative design approach (Goransson et. al. 2003) and by incorporating formative heuristic feedback from interface experts (Nielson, 1993). This more subjective approach described as "Usability Engineering" (Nielson, 1993) can help identify problems during display development and allows for trade-offs to be subjectively assessed. Evaluation is less prescriptive and is rather intended to find major problems and guide the design decision-making process. The Heuristic evaluation process will also be discussed in section 2.7. While this approach is good for identifying key problems or issues with existing interface design it does not generally produce quantified metrics or theories that can inform comparative design principles.

Table 2.5 Typical goals used to guide interface design and common user-experience criteria. (Preece, Rogers, and Sharp 2002)

Interface Design Goals	
USABILITY GOALS	**USER-EXPERIENCE CRITERIA**
Effectiveness	Satisfying
Efficiency	Enjoyable
Safety	Fun
Utility	Entertaining
Learnability	Helpful
Memorability	Motivating
	Aesthetically Pleasing
	Rewarding
	Emotionally fulfilling
	Supports creativity

Designing for the periphery is an important aspect of Ambient Information Systems than can be informed by other domains outside the scope of user interface design. Humans have two-vision systems namely central vision and peripheral vision (Sekuler & Blake, 1994). Thus streams of research from the field of perceptual and cognitive psychology that directly study the notion of ambient human perception and divided attentions are intrinsically related to the domain of Ambient Information Systems.

An important feature of Ambient Information Systems is the movement between the two visual systems, from primary focus to peripheral focus. Our primary vision accounts for a very small percentage of our vision overall with the ambient vision system accounting for the vast majority (Sekuler & Blake, 1994). The fact that the peripheral vision system does account for the majority of our visual perception supports the case for placing information in the periphery through technological means.

There has been research into the use animation in the periphery in order to maintain awareness (McCrickard, Catrambone & Stasko, 2001). An evaluation was performed in order to determine the distraction and comprehension of a range of peripheral displays that utilised a variety of animation methods such as fading and ticking. It was found from this evaluation that through placing animation in the periphery awareness of a set of metrics could be established without causing high levels of distraction, where users could still perform a primary task sufficiently in the presence of an Ambient Information System. This finding does align with the two vision systems as described by Sekuler & Blake and supports the notion that we have a natural ability to gather information through sources in our periphery without causing unnecessary distraction in relation to our central vision system.

User interface design is a very general field that applies to most computer systems. The three areas discussed next, "Information Decoration", "Ambient media" and "Tangible User Interfaces" are each more specific to the study of Ambient Information Systems. The relevance of these specific study areas is discussed next.

2.4.5 Information Decoration, Informative Art and Tangible User Interfaces

A recent field of study, called "Information Decoration" is described as a design concept that aims to find a balance between aesthetics and information quality (Eggen & Van Mensvoort, 2009). It is suggested that the advantage of Information Decoration is that it is centred on an objects ability to still be decorative, or aesthetically pleasing, even if the information it displays is not necessarily useful. Thus aesthetics is used as a trade-off against the potential for non-informative noise that can is added to the environment with such displays. Although Ambient Information Systems often have the goal of being useful information displays, these design principles of Information Decoration can be recognised as an integral aspect of Ambient Information Systems where displays are not only made to deliver information but also to be aesthetic objects that allows then to blend into the periphery.

Informative Art is defined as *"computer augmented or amplified works of art that not only are aesthetical objects but also information displays, in as much as they dynamically reflect information about their environment"* (Redstrom, et al., 2000). Informative Art highlights the possibility of enhancing pictures, posters and traditional art objects with digital information sources in various public and private spaces.

Informative Art starts with existing art works that are then "amplified" with information. This information would not normally be accessible to users of that space. There is some debate whether such displays classify as artworks in their own right although they do bare a relationship with the artistic practice known as "Information Art" or "Informatism" (Wilson, 2003). This type of art is typically characterised by a synergy of computing and information, and employs various electronic media to derive artworks from large datasets. The original emphasis of Informative Art was not necessarily on improving the aesthetic qualities of the work but on leveraging existing artistic qualities, particularly in terms of encouraging reflection or insight.

The ideas around Informative Art were developed at the same time as early Ambient Displays and hence have a close relationship with Ambient Information Systems. This design approach departs from key design goals of Information Visualisation as the intention is not specifically to find the most useful representation of the data but simply to suggest, perhaps abstractly, some underlying quality of the data source. The mappings used to create such displays may not necessarily be intuitive to the viewer. The intention is not necessarily to reduce cognitive workload nor to fill a particular work goal but simply to inspire thought about the underlying data.

"Tangible User Interfaces" are computer systems where user interaction is gained through physical objects in the real world (Ishii & Ullmer, 1997). There are two basic approaches suggested for developing this style of interaction. Firstly, is the notion of providing "Tangible Bits" which enables input via grasping and manipulating naturally occurring objects in the real world (Ishii & Ullmer, 1997). The second approach provides output via "Ambient Media" which augments the environment with appropriate peripheral displays (Ishii & Ullmer, 1997). While the use of interaction is not usually a critical part of Ambient Information System, as these tend to be designed for passive display of data, the concept of Ambient Media clearly encapsulates the ideas of an Ambient Information Systems.

Ishii and Ullmer define the concept of Ambient Media as the "*use of ambient media such as sound, light, airflow, and water movement for background interfaces with cyberspace at the periphery of human perception.*" (Ishii & Ullmer, 1997).

This notion of Ambient Media in itself lends to the creation of displays that use a varying array of information mediums. This is illustrated in Ishii & Ullmer's ambientROOM an environment that enables the use of light, sound, water flow and shadows to convey information to the room's occupant (Ishii & Ullmer, 1997). In the "Ghostly Presence" application, the ambientROOM is used to display information related to the remote activity of people through the use of shadows (Ishii & Ullmer, 1997).

By contrast, the "Hello.Wall" application uses light as the display medium (Prante et al., 2003. A series of LED lights are affixed to a wall in order to deliver information through the user's periphery. Often the Ambient Media itself directly reflects an aesthetic that is influenced by the various and quite broad types of media being used. (See table 2.6 for some further examples of different Ambient media).

The contrasting use of Ambient Media is abundant throughout the literature with a display such as AudioAura utilising audio to convey information to the user (Mynatt, Back, Want, Baer & Ellis, 1998), PlantDisplay (Kuribayashi & Wakita, 2006) using the metaphor of the growth of a real life plant to convey data flow and InfoCanvas using a range of two dimensional graphics on an LCD screen to map a number of metrics (Miller & Stasko, 2001).

With many possibilities around Ambient Media, one question that arises is the comparative effectiveness of one type of medium over another. This is particularly interesting concern for Ambient Information System design where various novel displays or "smart objects" are becoming readily available, along with the proliferation of various mobile technologies and the increasing presence in many environments of larger, but more traditional computer screen displays.

This question was addressed in an experiment where a tangible Ambient Information System the "Nabaztag Rabbit" was compared to a screen based display using a similar metaphor (Mirlacher, Buchner, Förster, Weiss & Tscheligi, 2009). It was found that there was little correlation between the medium used to convey the information and the information transmission ability of the display itself. Moreover it was discovered that the perceived "likability" of the display conveyed a positive correlation between its usability. This result reinforces the notion that good aesthetics, which may increase the "likeability" of an Ambient Information System, should be considered in a display's design.

In reviewing the literature it is clear that Ishii & Ullmer's (1997) early descriptions of Ambient Media permeate the literature with many examples of Ambient Information Systems adopting sound, light, airflow or water movement in order to place information in the user's periphery (see Table 2.6 for examples). It also clear that the media used for information transmission in Ambient Information Systems is much wider than Ishii & Ullmer's (1997) original definition, as multiple examples, such as ResearchWave (Hinrichs, Fisher & Riche, 2010) or Butterfly/Dragonfly (Nesbitt & Shen, 2007) use traditional 2D screen based displays as the implementation platform (see Table 2.6 for more examples).

Table 2.6 Some examples of the variety of Ambient Media used in Ambient Information Systems. Note the prevalence of traditional 2D computer displays.

Ambient Information System	Ambient Media	Reference
InfoCanvas	2D graphics screen based	(Miller & Stasko, 2001)
Informative Art	2D graphics screen based	(Redstrom, et al., 2000)
Mondrian Bus Display	2D graphics screen based	(Skog, Ljungblad & Holmquist, 2003)
The Digital Family Portrait	2D graphics screen based	(Mynatt, Rowan, Craighill & Jacobs, 2001)
Carenet display	2D graphics screen based	(Consolvo, Roessler & Shelton, 2004)
ResearchWave	2D graphics screen based	(Hinrichs, Fisher & Riche, 2010)
Breakaway	2D graphics screen based	(Jafarinaimi, Forlizzi, Hurst & Zimmerman, 2005)
The Ambient Calendar	2D graphics screen based	(Phelan, Coyle, Stevenson & Neely, 2008)
AmbientMirrors	2D graphics screen based	(Nakajima & Lehdonvirta, 2013)
Shopping Display	2D graphics screen based	(Reitberger, Obermair, Ploderer, Meschtscherjakov & Tscheligi, 2007)
AmbientNEWS	2D graphics screen based	(Valkanova, Moghnieh, Arroyo & Blat, 2010)
Ubi Fit	2D graphics screen based	(Consolvo et al., 2008)
Butterfly/Dragonfly	2D graphics screen based	(Nesbitt & Shen, 2007)
MoneyColor	2D graphics screen based	(Eades & Shen, 2004)
Fisherman	2D graphics screen based	(Shen, Eades, Hong & Moere, 2007)
Ceiling Ambient Display	Projected 2d graphics	(Tomitsch, Grechenig & Mayrhofer, 2007)
MoneyTree	3D graphics screen based	(Eades & Shen, 2004)
The Information Percolator	Bubbles	(Heiner, Hudson & Tanaka, 1999)
LumiTouch	LED lights	(Chang, Resner, Koerner, Wang & Ishii, 2001)

Tea Place	LED lights	(Lee, Cho, Park & Hahn, 2007)
Hello.Wall	LED Lights	(Prante et al., 2003)
Show-me	LED lights	(Kappel & Grechenig, 2009)
PhantomParasol	LED Lights	(Tsukada & Masui, 2006)
MoveLamp	Light	(Fortmann, Stratmann, Boll, Poppinga & Heuten, 2013)
The Power-Aware cord	Light	(Gustafsson & Gyllenswärd, 2005)
Follow the lights	Light	(Rogers, Hazlewood, Marshall, Dalton & Hertrich, 2010)
AmbientROOM	Light, sound, water flow and shadows	(Ishii et al., 1998)
Water Lamp	Light projections	(Dahley, Wisneski & Ishii, 1998)
Nabaztag Rabbit	Light, sound, movement	Mirlacher, Buchner, Förster, Weiss & Tscheligi, 2009
The Clouds	Physical object movement	(Rogers, Hazlewood, Marshall, Dalton & Hertrich, 2010)
Breakaway	Moving paper sculpture	(Jafarinaimi, Forlizzi, Hurst & Zimmerman, 2005)
Dangling String	Tangible object movement, sound	(Weiser & Brown, 1997)
Pinwheels	Pinwheel movement	(Dahley, Wisneski & Ishii, 1998)
AudioAura	Audio	(Mynatt, Back, Want, Baer & Ellis, 1998)
PlantDisplay	Living plant	(Kuribayashi & Wakita, 2006)

Through analysing the Ambient Information Systems in the literature it has become evident that the majority of displays use some form of light for their Ambient Media. For the case of screen-based displays it is clear that this light-based visualisation style is most commonly achieved through the use of 2D graphics on an LCD screen. Further knowledge on the use of screen based Ambient Information Systems could be gained if methods beyond two-dimensional graphics were explored. For example visualisations that incorporate 3D renderings are almost non-existent in the current domain of Ambient Information Systems. Thus in this research the WaveWatch display will focus on developing 3D rendered scenes although they will still be displayed on traditional 2D computer screens.

In summary, Ishii and Ullmer's (1997) definition of Ambient Media does encompass a large portion of the visualization modes utalised by tangible Ambient Displays in the literature. Although the intention of Ambient Media is clear through Ishii and Ullmer's definition, the question of how to best to classify the various types of Ambient Information Systems along different design dimensions still exists. Having covered the various fields that inform Ambient Information Systems we address the issue of categorising these displays in the next section.

2.5 Classifications of Ambient Information Systems

A broad range of Ambient Information Systems have been discussed in the previous sections all falling within Ishii and Ullmer's definition of Ambient Media (Ishii & Ullmer, 1997). We have discussed various motivations, different physical characteristics and also different interaction or ambience levels in these various displays. However, it has been suggested that there is a need for further classifications of these systems to help understand the design space of Ambient Information Systems and also to allow for better comparative analysis of the various types of systems (McCrickard et al, 2003; Matthews et al, 2004; Pousman & Stasko, 2006). The intention of this section is to review various taxonomies that have been used in the description of Ambient Information Systems.

Previously a number of formal design dimensions for Ambient Information Systems have been discussed in the literature. These discussions are motivated by questions that Nesbitt & Shen (Nesbitt & Shen, 2007) attempted to answer around "how to design a good ambient display?" and "when is an ambient display good?". While these questions are simple in their premise there are numerous attempts throughout the literature to define the design attributes that are required in order to create a "good" Ambient Information System. Many authors who write about creating an Ambient Information System also discuss ideal design dimensions but there is also another stream of research focusing solely on the design dimensions of such displays. Various design dimensions of Ambient Information Systems are summarised (see Table 2.7) and discussed in more detail below.

Table 2.7 Various Design Dimensions of Ambient Information Systems

Design Dimensions	Number of Dimensions	Year	Authors
Intrusiveness, Notification, Persistence, Temporal context, Overview to detail, Modality, Level of abstraction, Interactivity, Location, Content and aesthetics	11	2002	(Ames & Dey, 2002)
Notification, Transition, Abstraction	3	2002	(Matthews, Rattenbury, et al. 2002)
Interruption, Reaction, Comprehension	3	2003	(McCrickard et al, 2003)
Personalized, Flexible, Consolidated, Accurate, Appealing	5	2004	(Stasko, Miller, Pousman, Plaue & Ullah, 2004)
Abstract, Non-intrusive, Public, Aesthetic	4	2005	(Jafarinaimi, Forlizzi, Hurst & Zimmerman, 2005)
Information Capacity, Notification Level, Representational Fidelity, Aesthetic Emphasis	4	2006	(Pousman & Stasko, 2006)
Distraction, Comprehension, Usefulness, Interoperability	4	2007	(Nesbitt & Shen, 2007)
Abstraction level, transition, notification level, temporal gradient,	9	2007	(Tomitsch, Kappel, Lehner & Grechenig, 2007

Abstract, playful, Attractive	3	2010	(Rogers, Hazlewood, Marshall, Dalton & Hertrich, 2010)
Implicit interaction, Ambient persuasive visual expression, Emotional engagement	3	2011	(Nakajima & Lehdonvirta, 2011)

When viewing these previous design dimensions it is evident that several commonalities emerge, namely around aesthetic appeal and intrusiveness. While there are slight differences between design dimensions, the similarities are more evident revealing that even through formal design dimensions (Nesbitt & Shen, 2007; Ames & Dey, 2002) are not always utilised, the design concerns of such displays are often similar due to the common aspiration to develop displays that are aesthetically pleasing and non-intrusive.

In the following sections we discuss the formal frameworks that have been created to help categorise Ambient Information Systems (McCrickard et al, 2003; Matthews et al, 2004; Pousman & Stasko, 2006) and discuss the similarities and differences of each.

2.5.1 Intrusiveness, Notification, Persistence, Temporal context, Overview to detail, Modality, Level of abstraction, Interactivity, Location, Content and Aesthetics

One of the earliest examples of a taxonomy related to the design features of Ambient Information systems used eleven distinct dimensions (Ames & Dey, 2002). This broad list of eleven potential design dimensions specific to Ambient Information Systems include: Intrusiveness, Notification, Persistence, Temporal context, Overview to detail, Modality, Level of abstraction, Interactivity, Location, Content and Aesthetics (Ames & Dey, 2002). A description of each of these eleven dimensions is provided in Table 2.8.

Table 2.8 – Description of each of Ames & Dey's (2002) design dimensions.

Design Dimension	Description
Intrusiveness	Ambient Information Systems do not require constant attention from the user but convey information with differing levels of intrusiveness dependent on the significance of the data.
Notification	Displays can move from the periphery to the centre of the user's attention when required. Changes in information are conveyed subtly to the user.
Persistence	Information is shown on the display using an appropriate time scale and refresh rate.
Temporal Context	Contextual information is provided by the display if comparisons with past or predictions of future information are present.
Overview to detail	Displays show sufficient information in order for the user to gather knowledge at a glance. More detail is provided to the user if they pay attention.
Modality	Displays provide information through a sensory channel that is not already overloaded.
Level of abstraction	Information is conveyed through an abstract or indirect manner. The display's visualisation should be related to the nature of the information.
Interactivity	Displays employ an appropriate level of user interaction, without being overly demanding on the part of the user.

Location	The design of such a display addresses the location in which it will be installed.
Content	Displays convey information that users care about.
Aesthetics	Displays are aesthetically pleasing.

An Ambient Information System that exemplifies each of Ames & Dey's design dimensions is Nimio (Brewer, Williams & Dourish, 2005). Nimio is a tangible Ambient Information System taking the form of silicone pyramid, cube, triangular prism or square prism. The display is paired with a series of other Nimio devices that output LED light when another Nimio is interacted with. Sensing hardware is embedded in each Nimio in order to capture and then visualise the activity of users within the vicinity of each device. The design of the Nimio does incorporate each of Ames & Dey's design dimensions as seen in table 2.9.

Table 2.9 – Nimio's incorporation of Ames & Dey's design dimensions

Design Dimension	Nimio's Implementation
Intrusiveness	The Nimio display is unobtrusive in that it can function without input from the user and has limited alarming capabilities.
Notification	The Nimio is capable of moving from the periphery to the centre of the user's attention through its use of LED lights to convey data.
Persistence	Each Nimio device displays data in real time.
Temporal Context	No temporal context information is delivered through the device.
Overview to detail	Few pieces of information are delivered through the Nimio display.
Modality	The Nimio display uses light for data conveyance. This use of this light may or may not overall load the senses of the user, depending on a number of environmental factors.
Level of abstraction	Nimio uses abstract symbols to convey data.
Interactivity	The Nimio does incorporate interaction, where accelerometers in the device are used to determine if it is being held or moved by a user. This information is visualised by other paired Nimios.
Location	The Nimio devices were implemented into an office environment.
Content	The display does convey information that a user could find useful in relation to the presence and movements of their colleagues around an office setting.
Aesthetics	Nimio is an aesthetic device taking on the form of an interactive silicon sculpture.

The design dimensions proposed by Ames and Dey encompass several attributes that are common to Ambient Information Systems but also include concepts directly related to Calm Technology, user Interface Design and evaluation. For example, emphasis is put on Intrusiveness and Notification in relation to such displays being non-alarming, which is a key concern of Calm Technology.

Furthermore several of the design dimensions such as Temporal Context, Overview of details and Content are similar to some of Nielson's usability heuristics (Nielsen, 2005)

Many of these design dimensions also overlap with various design intentions of systems that have been built. For example, the design motivations given for the Breakaway display were noted as being abstract, non-intrusive, public and aesthetic (Jafarinaimi, Forlizzi, Hurst & Zimmerman, 2005) where these are encapsulated in the design dimensions proposed by Ames & Dey (2002).

2.5.2 Notification, Transition, Abstraction

While the previous taxonomy includes the dimension of Intrusiveness and Overview to detail they do not focus directly on a key aspect of Ambient Information Systems, namely that they sit on the periphery of attention. Indeed this has led to Ambient Information Systems also being described by some authors as Peripheral Displays, or "*displays that show information that a person is aware of, but not focused on*" (Matthews et al, 2004).

A taxonomy was derived to help categorise the design of Peripheral Displays and this was subsequently integrated into a Peripheral Display Toolkit (Matthews, Rattenbury, et al. (2002). This taxonomy focused on cognitive psychology models of attention and dividing this key concept of attention into four main states: preattention, inattention, divided attention, and focused attention. Stimuli attended to in the early preattentive phase are processed without contextual reference, go unnoticed and as such do not affect the viewer's perception. By contrast during the inattention state, perceptual stimuli may affect behavior even though they are processed subconsciously. The final two states, divided attention and focused attention, relate to perceived stimuli that are processed consciously but using in either a singular or multi-tasking fashion.

This taxonomy uses three dimensions, namely Notification Level, Transition and Abstraction to classify displays. In this taxonomy, *Abstraction* refers to the way incoming data is transformed to meet the requirements of the output device (Matthews, Dev, et al, 2004). It defines two distinct types of data abstraction used in displays, either degradation or feature extraction. Degradation ignores some original data by reducing the fidelity of the data. Feature extraction concerns the refinement of data or derivation of new measures from the underlying data. This *abstraction* dimension might be described as the data mapping part of design for Ambient Information Systems and is a common step in Information Visualisation.

In this taxonomy the *Notification Level* of the incoming data is further used to define the display and can be described as “demand action”, “interrupt”, “make aware”, “change blind”, and “ignore” (Matthews et al, 2004). A “demand action” notification requires that the user perform some action to stop the alerting, thus requiring the refocus of a user’s primary attention to respond. An “interrupt” is of slightly lower priority and is characterized as an attempt to obtain the user’s focused attention. The “make aware” data is of slightly lower priority but like the “interrupt” class of data will signify the need for divided attention from the user. The “change blind” corresponds to inattention, and as such should attempt to not distract the user’s conscious primary attention. Finally, the “ignore” category represents data that should not be displayed, and should not correspond to any attention level.

Ambient Information Systems are peripheral displays that fall into the “make aware” notification level. Only very critical information would require the user to be alerted, to drop everything and attend to the displayed information. This is not in general the design goal of Ambient Displays. It does imply that Ambient Information Systems could change notification level based on the changes to incoming data over time. The lower notification levels correspond to less critical data and thus should be displayed in a manner that does not allow peripheral changes in the display to distract the user’s attention away from their primary task.

The third part of this taxonomy describes the *Transitions,* such as fading or movement that are used to update the states of the information display. These should be designed to attract an appropriate amount of attention on the basis of the notification level of the underlying data, the sensory modality of the display and taking into account context such as the background noise in area of the display. Abrupt transitions can be used for their alerting function when changes “demand action” or are designed to “interrupt”. By contrast "minimally attended" displays such as those seen in Ambient Information Systems with “make aware” and “change blind” notifications should adopt subtler or repetitive transitions that are just noticeable but not distracting.

As can be seen from this discussion the Notification, Transition and Abstraction taxonomy while applicable to Ambient Information Systems also includes many additional displays that while peripheral are designed to act as alarms or to have alerting functionality. In these cases the underlying data may even be categorized as critical to some divided attention task and as such displays might be more carefully designed to allow monitoring rather than having the vague goal of awareness that is described for many Ambient Information Systems. This monitoring is arguably outside the intended functionality of Ambient Information Systems.

One further noticeable shortcoming in this taxonomy is arguably the decision to not include aesthetics, an important design goal suggested for any Ambient Information System.

2.5.3 Interruption, Reaction, Comprehension

Another taxonomy that includes Ambient Information Systems is based on a review of typical user goals and constraints for notification systems (McCrickard et al, 2003). *Notification systems* are defined *"as interfaces that are typically used in a divided-attention, multitasking situation, attempting to deliver current, valued information through a variety of platforms and modes in an efficient and effective manner"* (McCrickard & Chewar 2003).

This categorization by McCrickard et al (2003) has foundations in theories related to human information processing and was devised to provide a unifying model that can be used to guide evaluation for such notification systems. The taxonomy is based on the three dimensions of interruption, reaction, and comprehension. These dimensions are considered critical in interfaces designed to support divided attention or multi-tasking by users when monitoring real-time data (McCrickard et al, 2003).

Interruption is the expected level of distraction or intrusion required from some primary task to events in the background-monitoring task. *Reaction* refers to the speed and accuracy of response expected to a given interrupting stimulus. *Comprehension* relates to need for the design to assist remembering and important it is for the user to directly interpret patterns in the display. Each of these three dimensions is rated on a scale from low (0) to high (1). Considering the maximum and minimum values of these three dimensions allows for the definition of eight idealised models or design patterns (see table 2.10).

For example, in this taxonomy Ambient Information Systems would be specified with a low level of Interruption and a low expectation for the user to react quickly and accurately. However such displays must have a high level of comprehension or memorability so the patterns can be processed at a later time. By contrast Alarms and Critical Information Monitors would be expected to have both a high interruption and level of reaction specified as part of their design goals.

Table 2.10 Idealised models or design patterns used to categorise Notification Systems (McCrickard et al, 2003)

Display Type	Interruption	Reaction	Comprehension
Noise	0	0	0
Ambient Media	0	0	1
Indicator	0	1	0
Secondary Display	0	1	1
Diversion	1	0	0
Information Exhibit	1	0	1
Alarm	1	1	0
Critical Activity Monitor	1	1	1

Once again this taxonomy covers a broader range of systems of which Ambient Information Systems is only a smaller part. It has the benefit of suggesting a cognitive process model that allows for design specification in terms of user goals and interaction constraints such as context, information complexity and cognitive workload. It also supports comparative evaluation studies to be carried out for systems that can be defined in terms of the three dimensions that make up the framework. However, the framework explicitly excludes key criteria of Ambient Information Systems such as aesthetics and subjective satisfaction or enjoyment as primary dimensions (McCrickard et al, 2003)

2.5.4 Information, Notification, Representation, Aesthetics

Probably, the most well known classification of Ambient Information Systems in the literature defines four key dimensions that can to use help categorize these systems. These four design dimensions are: Information Capacity, Notification Level, Representational Fidelity, and Aesthetic Emphasis (Pousman & Stasko, 2006). Pousman & Stasko's taxonomy is effective in that it not only defines a set of design dimensions, it also allows each of the dimensions to be given a nominal ranking (from low to high) in relation to a particular Ambient Information System. Each dimension is ranked using the five categories of low, somewhat low, medium, somewhat high and high. Although how these are interpreted varies considerably between the four dimensions (see table 2.10).

Information Capacity relates to the number of information sources that an Ambient Information System can visualise at any one time. For example, a display that only displays one data element would receive a ranking of low for Information Capacity, while a display that encodes twenty or more data elements would receive a ranking of high.

Notification level represents the level to which an Ambient Information System can alert or interrupt a user. For this dimension the five categories can be understood as ignore (low), Change blind (somewhat low), Make aware (medium), Interrupt (somewhat high) and Demand Attention (high).

For example a display such as the Water Lamp would have a low level of notification due to its ability to not interrupt the user unnecessarily through its use of subtle light and shadows to convey data (Wisneski et al., 1998). On the other end of the spectrum a display such as Mobile Bus could be rated as having a somewhat high level of notification due to its use of movement that could easily attract the attention of an individual (Mankoff & Dey, 2003).

Representational fidelity describes how an Ambient Information System encodes the data it displays. This can range from very realistic representations using photographs or cartographic maps to the quite abstract use of symbols to represent the underlying data. For this dimension the five categories can be specified as symbolic - abstract symbols (low), symbolic – letters and numbers (somewhat low), iconic – metaphors (medium), iconic – drawings, doodles, (somewhat high) and indexical – maps and photographs (high). Examples exist throughout the literature of differing implementations of representational fidelity. A display such as the Information Percolator would have a low level of Representational fidelity due to its use of abstract symbols (bubbles) to convey data to the user (Heiner, Hudson & Tanaka, 1999). The bus mobile is an example of a display that could be classified as having somewhat low representational fidelity due to its use of letters and numbers in order to deliver contextual information to the user (Mankoff & Dey, 2003). The Butterfly/Dragonfly display uses the metaphor of a butterfly being positive and a dragonfly being negative in order to deliver information to the user, giving it a representation fidelity classification of medium due to its reliance on metaphors for information transmission (Nesbitt & Shen, 2007). The InfoCanvas display is capable of exemplifying both somewhat high and high levels of representational fidelity through its ability to convey information through icons as well as photographs (Miller & Stasko, 2001)

Aesthetic Emphasis, the final axis of this taxonomy represents the level of effort to which a display aims to be an aesthetic rather than simply functional object. Once again, the categories of low, somewhat low, medium, somewhat high and high are used to position displays on this dimension. The measure is intended to relate to the designer's intention rather than being some absolute measure of a display's aesthetic worth. A display such as InfoPulse could be classified as having a low level of aesthetic emphasis due to its design not being overly focused on aesthetics. (Migicovsky, 2008). Representing the opposite end of the scale, Informative Art displays such Butterfly/Dragonfly (Nesbitt & Shen, 2007) have high levels of Aesthetic Emphasis due the levels of design effort put into making the display not only convey information but also be an aesthetic object.

Table 2.11 Ranking categories used for the four different design dimensions (Pousman & Stasko, 2006).

Nominal Categories (used for Information Capacity and Aesthetic Emphasis)	**Notification level**	**Representational Fidelity**
High	Demand Attention	Indexical – Maps Photographs
Somewhat High	Interrupt	Iconic – Drawings, doodles
Medium	Make aware	Iconic – Metaphors
Somewhat low	Change blind	Symbolic – Letters and numbers
Low	Ignore	Symbolic – Abstract symbols

The Pousman & Stasko's taxonomy has many overlaps with other taxonomies in terms of its design dimensions. However, it remains one of the best-known classifications specifically described for Ambient Information Systems and we will also adopt it to use in our own research with the WaveWatch display. Arguably one of the reasons it is well known in the field is the identification of various design patterns based on the four dimensions. In the next section we briefly review the concept of a design pattern before describing the original design patterns that were first used to classify Ambient Information Systems (Pousman & Stasko, 2006). We will then extend this previous work by categorising further Ambient Information Systems into these design patterns and by updating the original work of Pousman & Stasko (2006). This process will help us identify a new design pattern based on this taxonomy that will be discussed later (section 2.6.2).

2.6 Design Patterns for Ambient Information Systems

One way to solve common design problems is to adopt, or adapt, a solution that has been useful in the past. This is true of Ambient Information Systems as it is in other design domains. Design patterns are intended as a more formal way of capturing good designs, or design practices, so they can be reused. They also help categorise designs to allow better comparison on various design features.

The approach of using formal design patterns is attributed to Christopher Alexander who described over 250 problems in architecture along with descriptions and solutions (Alexander et. al. 1977). These problems and solutions together formed a "pattern language" for communicating good design practice. In architecture, such design patterns were identified at many scales and were frequently applied together to solve specific design problems. The second community to broadly adopt the notion of design patterns was the Object-oriented software industry where it has been extensively used (Erich et. al, 1995). The approach has also been described in other design domains such as auditory display design (Barrass, 2003), computer game design (Ng & Nesbitt, 2013) and even the more general field of creativity (Nesbitt, 2013)

Pousman & Stasko (2006) used this approach to describe four particular patterns, based on the design dimensions of their taxonomy to describe Ambient Information System. The four design patterns were Sculptural Symbolic Displays (table 2.12, 2.16), Multiple Information Consolidators (table 2.13, 2.17), Information Monitor Displays (table 2.14) and High Throughput Textual Displays (table 2.15).

Symbolic Sculptural Displays are displays that typically display a single metric to the user through sculptural means (Pousman & Stasko, 2006). A good example of a Symbolic Sculptural display is the Dangling String (Weiser & Brown, 2006). See table 2.16 for more examples of this design pattern.

Multiple Information Consolidators are displays that are able to deliver many pieces of information to the user. Displays that are considered as being Multiple Information Consolidators are typically screen based as this allows multiple data sources to be more easily integrated into the display's design. The InfoCanvas (Miller & Stasko, 2001) is a good example of this type of display. See table 2.17 for more examples of this design pattern.

Information Monitor displays are Ambient Information Systems that are displayed as part of a user's desktop computer environment. The High Throughput Textual Display constitutes a display that uses simple graphics such as icons or text in order to deliver information to the user. Throughput Textual Display's are capable of conveying many metrics to the user but have little focus on aesthetics.

Table 2.12 Design dimension mappings for Symbolic Sculptural Displays.

	Information Capacity	Notification Level	Representational Fidelity	Aesthetics
High				
Somewhat high				
Medium				
Somewhat low				
Low				

Table 2.13 Design dimension mappings for Multiple Information Consolidator

	Information Capacity	Notification Level	Representational Fidelity	Aesthetics
High				
Somewhat high				
Medium				
Somewhat low				
Low				

Table 2.14 Design dimension mappings for Information Monitor Display

	Information Capacity	Notification Level	Representational Fidelity	Aesthetics
High				
Somewhat high				
Medium				
Somewhat low				
Low				

Table 2.15 Design dimension mappings for High-Throughput Textual Display

	Information Capacity	Notification Level	Representational Fidelity	Aesthetics
High				
Somewhat high				
Medium				
Somewhat low				
Low				

2.6.1 Categorising previous displays using design patterns

This section considers the utility of Pousman & Stasko's (2006) design patterns by re-examining the distribution of existing Ambient Information Systems from the literature in terms of their four design patterns. The tables below (table 2.16, table 2.17, table 2.18) rank a subset of the Ambient Information Systems from the literature against each axis of the taxonomy. Each table is grouped by a set of displays that fall under the same design pattern. The classification levels of the design dimensions are ranked using numbers from one to five (one for low, 2 for somewhat low, 3 for medium, 4 for somewhat high and 5 for high).

The displays ranked in table 2.15 embody the design features of Sculptural Symbolic Displays in that they all have a high level of aesthetic emphasis but low levels of information capacity and notification. Furthermore all the displays in table 2.15 are tangible, aesthetic objects as has been previously suggested for this design type (Pousman & Stasko, 2006)

The displays in table 2.16 have been classified as Multiple Information Consolidators due to their ability to convey many metrics to the user through a display that is moderately concerned with aesthetics. Each of the displays that fall under this design dimension are screen-based, highlighting the utility of such displays to convey many data elements to the user.

In reviewing the literature there are a lack of displays exemplifying the design attributes of Information Monitor and High Throughput Textual Displays. These design patterns are not explored in depth due to such displays lacking the typical features of Ambient Information systems as explained through traditional definitions.

The Ambient Information Systems in table 2.18 all hold similar attributes when ranked against the axes of Pousman & Stasko's taxonomy, but do not fit into any of the four currently defined design types. The displays convey too many information elements to be considered as Sculptural Symbolic Displays but not enough to be considered as Multiple Information Consolidators.

The trend emerges that the unclassifiable displays typically have low to medium information capacity, rely on metaphors for information transmission and are highly aesthetic. The examples of displays from the literature that embody these features are typically screen based and utilise the metaphor of Informative Art, where general awareness of data is the goal.

Table 2.16 Sculptural Symbolic Displays

Display	Year	Information Capacity	Notification Level	Representational Fidelity	Aesthetics
Digital Family Portrait (Mynatt, Rowan, Craighill & Jacobs, 2001)	2001	2	2	1	4
CareNet (Consolvo, Roessler & Shelton, 2004)	2004	2	2	1	4
Information Percolator (Heiner, Hudson & Tanaka, 1999)	1999	2	2	1	4
Hello.Wall (Prante et al., 2003)	2003	2	2	1	4
Water Lamp (Dahley, Wisneski & Ishii, 1998)	1998	1	2	1	4
Pinwheels (Dahley, Wisneski & Ishii, 1998)	1998	1	2	1	4
LumiTouch (Chang, Resner, Koerner, Wang & Ishii, 2001)	2001	1	2	1	4
Tea Place (Lee, Cho, Park & Hahn, 2007)	2007	1	2	1	4
Ambient Orb (Ambientdevices.com, 2015).		1	2	1	4
Nimio (Brewer, Williams & Dourish, 2005)	2005	1	2	1	4
Dangling String (Weiser & Brown, 1996)	1996	1	2	1	4
Power-Aware Cord (Gustafsson & Gyllenswärd, 2005)	2005	1	2	1	4
Follow the lights (Rogers, Hazlewood, Marshall, Dalton & Hertrich, 2010)	2010	1	2	1	4
The Clouds (Rogers, Hazlewood, Marshall, Dalton & Hertrich, 2010)	2010	1	1	1	4
Show me (Kappel & Grechenig, 2009)	2009	1	3	3	4
Breakaway (Jafarinaimi, Forlizzi, Hurst & Zimmerman, 2005)	2005	1	2	3	4
MoveLamp (Fortmann, Stratmann, Boll, Poppinga & Heuten, 2013)	2013	1	2	3	4

PlantDisplay (Kuribayashi & Wakita, 2006)	2006	1	1	3	4
Bus Mobile (Dey, Mankoff & Dey, 2003)	2003	2	4	1	1

Table 2.17 Multiple Information Consolidators

Display	Year	Information Capacity	Notification level	Representational Fidelity	Aesthetics
AmbientNews (Valkanova, Moghnieh, Arroyo & Blat, 2010)	2010	5	3	2	3
ResearchWave (Hinrichs, Fisher & Riche, 2010)	2010	5	3	2	3
InfoCanvas (Miller & Stasko, 2001)	2001	5	3	3	3
Ambient Calendar (Phelan, Coyle, Stevenson & Neely, 2008)	2008	5	3	3	3
Time Management (Occhialini, van Essen & Eggen, 2011)	2011	4	3	1	3
Exercise Awareness Display (Fujinami & Riekki, 2008)	2008	4	3	3	3

Table 2.18 Unclassifiable using existing taxonomy

Display	Year	Information Capacity	Notification Level	Representational Fidelity	Aesthetics
Informative Art (Redström, Skog & Hallnäs, 2000)	2000	2	3	3	5
Mondrian Bus (Skog, Ljungblad & Holmquist, 2003)	2003	2	3	3	5
Butterfly/ Dragonfly (Nesbitt & Shen, 2007)	2007	2	3	3	5
MoneyColor (Shen & Eades, 2005)	2005	2	3	3	5
Fisherman (Shen, Eades, Hong & Moere, 2007)	2007	2	3	3	5
Persuasive Art (Nakajima & Lehdonvirta, 2013)	2013	2	3	3	5
MoneyTree (Shen & Eades, 2005)	2004	2	3	3	4
Rabbit screen display (Mirlacher, Buchner, Föster, Weiss & Tscheligi, 2009)	2009	2	3	3	4
Celling Display (Tomitsch, Grechenig & Mayrhofer, 2007)	2007	2	3	1	4
Virtual Aquarium (Nakajima & Lehdonvirta, 2013)	2013	2	4	3	4
InfoPulse (Migicovsky, 2008)	2008	2	4	2	1

2.6.2 A New Design Pattern - Aesthetic Awareness Display

Due to the high number of displays that do not fit within the currently defined design types we propose a new design pattern, The *Aesthetic Awareness Display*. Aesthetic Awareness displays are highly aesthetic displays that display a moderate number of information sources to the user. Such systems use metaphors in order to encode data into the aesthetics of the display. Displays of this type are typically screen based but unlike Multiple Information Consolidators do not aim to deliver a high number of metrics to the user. Instead Aesthetic Information Displays focus on delivering few metrics in an aesthetically pleasing display indicating that they represent a middle ground between Sculptural Symbolic Displays and Multiple Information consolidators.

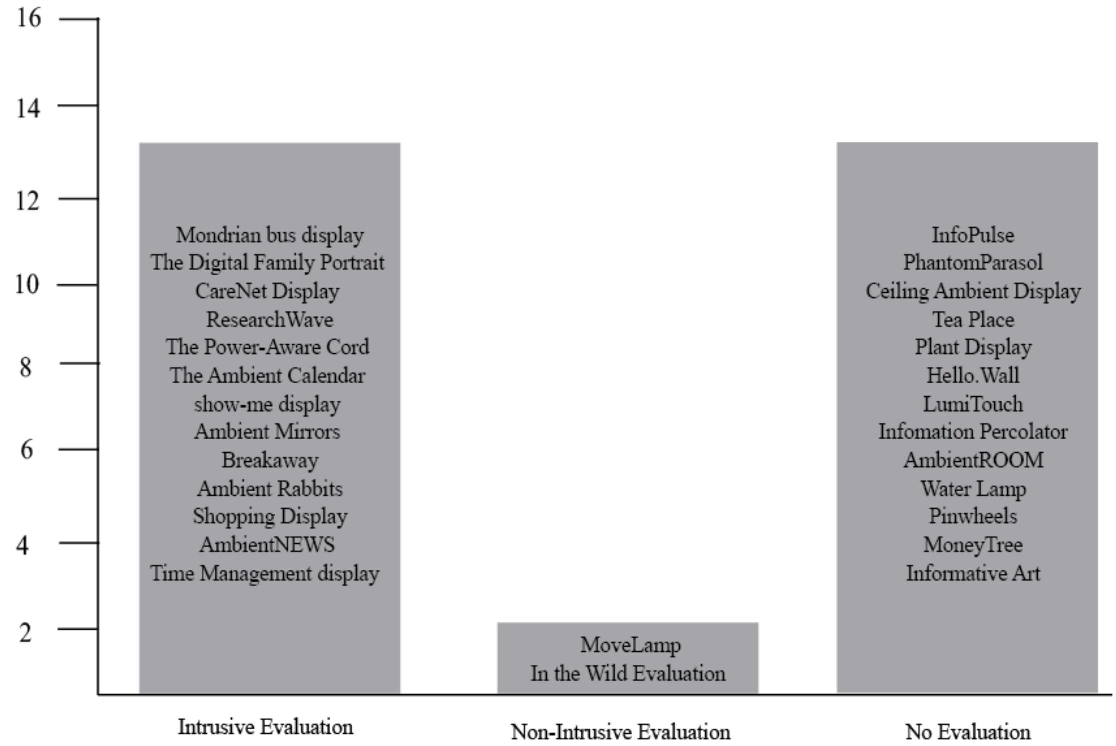
Table 2.19 Design Dimension mappings – Aesthetic Information Display.

	Information Capacity	Notification Level	Representational Fidelity	Aesthetics
High				
Somewhat high				
Medium				
Somewhat low				
Low				

2.7 Evaluating Ambient Information Systems

In analysing the literature related to Ambient Information Systems it is possible to find research related to the development, design and evaluation of Ambient Information Systems. Arguably, the stream of research that is least developed at this time pertains to the evaluation of Ambient Information Systems. In our review, approximately 50% of the reported Ambient Information Systems are not evaluated at all (see figure 2.6). Of those that are evaluated the evaluation methods are intrusive in the sense that the evaluation requires direct attention from the user. This in itself may be a problem for measuring the cognitive workload required of users in such displays and their ability to function at the periphery of a users attention.

Figure 2.6 The evaluation and non-evaluation of Ambient Information Systems



The lack of evaluation is also identified directly in the literature, where a key issue surrounding evaluation methods is the lack of knowledge around what makes one Ambient Information System more effective in presenting peripheral information than another (Mankoff et al., 2003). Indeed few evaluations have been performed on Ambient Information Systems (Skog, Ljungblad & Holmquist, 2003), displaying the lack of a universal evaluation method that can be applied to such displays in order to evaluate their effectiveness. Moreover there are few implementations of Ambient Information Systems that have not been solely used in a research setting (Nesbitt & Shen, 2007). While some formal evaluation methods focus solely on the scope of Ambient Information Systems, some displays have been evaluated using more generic, but less formal methods such as surveys or "Wizard of Oz" prototyping (Mynatt, Rowan, Craighill & Jacobs, 2001).

It is clear that more work in devising standard methods for evaluating the effectiveness and usability of Ambient Information Systems is required. That said, existing in the literature are a range of evaluation methods used for evaluating Ambient Information Systems which are discussed in this section.

2.7.1 Current Evaluation Methods

Broadly the current evaluation methods that exist can be grouped as being Intrusive Evaluations or Non-intrusive Evaluations (Shen, Eades, Hong & Moere, 2007). *Intrusive Evaluation* occurs when the evaluation process interrupts the normal behaviour of a user. For example, such formal evaluation methods usually consist of usability testing in a laboratory setting (Shen, Eades, Hong & Moere, 2007).

By contrast, a *Non-Intrusive Evaluation* occurs when the evaluation does not disturb the normal behaviour of the subject. For example, the use of video to record normal user behaviour. Such evaluations are usually conducted in situ over a long period of time (Shen, Eades, Hong & Moere, 2007). Although there are advantages in Non-Intrusive evaluation methods in terms of the level of disturbance placed on the user, there are currently few existing evaluation methods that take on this form (Shen, Eades, Hong & Moere, 2007).

Both of these evaluation methods differ in terms of the level of interruption placed on the user in order to complete the experiment. It is the intention that Ambient Information Systems operate in the periphery of a user's attention and be non-interrupting. Yet it has also been suggested that intrusive evaluations that interrupt user attention provide a better quantitative measurement than non-intrusive methods (Shen, Eades, Hong & Moere, 2007).

2.7.2 Invasive Evaluation Methods

Throughout the literature there are several evaluation methods that can be classified as being intrusive. These evaluation methods typically require a high level of involvement from the user, and often need to be undertaken in a laboratory environment rather than the intended, more natural, in-situ location of the system.

The Heuristic Evaluation of Ambient Displays (Mankoff et al., 2003) is one intrusive evaluation method that has had some support from the community (Phelan, Coyle, Stevenson & Neely, 2008). This approach adapts the Nielsen's heuristic evaluation methods (Nielsen, 2005) directly for the purpose of measuring the usability and effectiveness of Ambient Information Systems (Mankoff et al., 2003).

The adapted heuristics for evaluating Ambient Information Systems relate to the following key design features:

1. Useful and relevant information
2. “Peripherality” of display
3. Match between design of ambient display and environments
4. Sufficient information design
5. Consistent and intuitive mapping
6. Easy transition to more in-depth information
7. Visibility of state
8. Aesthetic and Pleasing Design

Many of these criteria for evaluation have been discussed previously in a review of proposed taxonomies for Ambient Information Systems. Mankoff’s third heuristic, namely to evaluate how well the design of an Ambient Display of a display matches into its environment (Mankoff et al., 2003) is also explored by in the literature through the idea of Ambient Counterparts (Schmidt, Gellersen & Beigl, 1999). Ambient Counterparts is a theory explaining that digital information has a natural counterpart in the physical world. In observing the Ambient Information Systems in the literature many displays do not employ the idea of Ambient Counterparts due to their often abstract and non-data related metaphors. Displays that employ the idea of Ambient Counterparts may perform better in relation to Mankoff’s third heuristic due to Ambient Counterparts focus on matching data with a befitting physical world metaphor. This could help an Ambient Information System not clash with its environment due to the digital data taking on the form of a natural counterpart in the physical world.

Like Mankoff, Shen proposes an evaluation methodology for Ambient Displays that adapts an existing framework, in this case, the DECIDE framework (Shen, 2007). The evaluation structure proposed by Shen focuses on measuring the effectiveness, comprehension and distraction performance of Ambient Displays (Shen, 2007).

The DECIDE framework while not outlining specific evaluation methods does act as a checklist which can assist in planning formal evaluations as well as help remind the evaluator of issues to think about around the evaluation (Preece, Rogers & Sharp, 2002). Due to the nature of the DECIDE framework it could be used for either intrusive or non-intrusive evaluations.

The modified version of the DECIDE framework was used to complete an intrusive evaluation of the MoneyColor System (Shen, 2007). Participants were instructed to play a game while also being in the presence of the Ambient Information System. Shen followed up on this experiment with a questionnaire as well as an interview in order to evaluate the display.

The MoneyColor System was evaluated in a formal laboratory environment. Indeed this approach is commonly used to gain subjective feedback about Ambient Information Systems. However, there are examples of these methods being used in conjunction with a deployment of the system in a more natural environment. For example, the evaluation of two Ambient rabbit displays (Mirlacher, Buchner, Förster, Weiss & Tscheligi, 2009) was carried out in this manner. In the case of the two Rabbit Ambient Displays, an interview and survey were used to perform the evaluation (Mirlacher, Buchner, Förster, Weiss & Tscheligi, 2009). As part of this evaluation process 32 participants where interviewed through a questionnaire.

In summary, surveys and questionaries are common intrusive evaluation methods that feature throughout the literature. The displays in the literature that were evaluated using this or similar intrusive techniques are listed in Table 2.20. While these evaluation methods are common between each of the studies, there are differences in what is being measured through the evaluation process, raising questions about the need for more standardized approaches or evaluation criteria for Ambient Information Systems.

Table 2.20 Examples of methods used to evaluate Ambient Information Systems

Display	Intrusive	Non Intrusive	Method	Reference
Mondrian bus display	Yes	No	Interview	(Redström, Skog & Hallnäs, 2000)
The Digital Family Portrait	Yes	No	Surveys /"Wizard of Oz" prototyping	(Mynatt, Rowan, Craighill & Jacobs, 2001)
CareNet Display	Yes	No	Interviews/questionnaires	(Consolvo, Roessler & Shelton, 2004)
ResearchWave	Yes	No	Survey	(Hinrichs, Fisher & Riche, 2010)
The Power-Aware Cord	Yes	No	Wizard-of-Oz experiment	(Gustafsson & Gyllenswärd, 2005)
The Ambient Calendar	Yes	No	Heuristic Evaluation – Survey based	(Phelan, Coyle, Stevenson & Neely, 2008)
Show-me display	Yes	No	In-situ questionnaire	(Kappel & Grechenig, 2009)
Ambient Mirrors	Yes	No	Interviews, survey/questionnaire	(Nakajima & Lehdonvirta, 2011)
Ambient Rabbits	Yes	No	Interviews/Surveys	(Mirlacher, Buchner, Forster, Weiss & Tscheligi, 2009)

Enhancing the Shopping Experience with Ambient Displays	Yes	No	In-situ interview	(Reitberger, Obermair, Ploderer, Meschtscherjakov & Tscheligi, 2007)
AmbientNEWS	Yes	No	Workshopping, interviews, informal observations, questionnaires	(Valkanova, Moghnieh, Arroyo & Blat, 2010)
Time Management display	Yes	No	Observations, questionnaires, interviews	(Occhialini, van Essen & Eggen, 2011)
In the Wild	Yes	Yes	Video recordings, semi-structured interviews	(Messeter & Molenaar, 2012)
MoveLamp	No	Yes	In-situ, use of pedometer	(Fortmann, Stratmann, Boll, Poppinga & Heuten, 2013)

2.7.3 Non-Intrusive Evaluation Methods

Characterised as an evaluation that involves no effort from the subject, such non-Intrusive evaluations are ideal for evaluating Ambient Information Systems in that they require no additional attention from the user (Shen, Eades, Hong & Moere, 2007).

Exemplifying a non-intrusive evaluation of an Ambient Information System is the study involving the MoveLamp display (Fortmann, Stratmann, Boll, Poppinga & Heuten, 2013). In this case, an in situ evaluation was conducted to evaluate the ability of the display to change the user's behaviour in relation to their walking activities. The evaluation consisted of users being exposed to the MoveLamp display for one day while wearing a pedometer and a numerical display of steps on another day. While the environment of the user changed due to the implementation of each display, the involvement from the user in order to undertake the evaluation was fairly low in comparison to intrusive evaluations such as that of The Ambient Calendar display (Phelan, Coyle, Stevenson & Neely, 2008) where users were required to fill out a formal survey. The attention and effort required from the user for the evaluation of the MoveLamp display was minimal as the evaluation data was generated automatically during their normal daily activities.

Another good example is the use of video recordings to collect data as occurred in the evaluation of the In the Wild display (Messeter & Molenaar, 2012). Despite the fact that non-intrusive evaluations can occur at the periphery of the user's attention, thus matching the modality of Ambient Information Systems, there are few examples of this type of evaluation available in the literature (see Table 2.20).

2.7.4 Evaluation Attributes

While many of the evaluation methods throughout the literature use similar methods most examples of evaluation differ in relation to what is being evaluated or measured. There is still a lack of universally utilised evaluation criteria for evaluating these displays. This issue was also identified in the various suggested taxonomies for Ambient Information Systems and reflects different design goals that Ambient Display designers aspire to.

The evaluation criteria tend to reflect the specific research questions or motivations of the study and some examples include:

- Comprehension and use evaluated (Skog, Ljungblad & Holmquist, 2003)
- Intuitiveness and perception/feedback on the different mappings (Gustafsson & Gyllenswärd, 2005)
- Focus on aesthetic design aspects (Valkanova, Moghnieh, Arroyo & Blat, 2010)

Despite the differences in evaluation criteria of Ambient Information Systems a formal set of evaluation attributes have been defined, namely Distraction, Comprehension, Usefulness and Interoperability (Nesbitt & Shen, 2007). Nesbitt & Shen in attempting to answer the question "When is an ambient display good?" developed the evaluation attributes in order to help design a display but to also evaluate the display against the same metrics. Although such evaluation attributes exist through Nesbitt & Shen's research and the development of heuristics for Ambient Information Systems, these methodologies are seldom used in favour of more ad-hoc evaluation criteria that is often defined through the purpose of the evaluated display. We conclude that insights into various design trade-offs for Ambient Information Systems could be gained through the wider use of common evaluation attributes.

2.8 Conclusions

Through an analysis of the literature insights into the domain of Ambient Information systems have been realised. In summarization Ambient Information systems are aesthetically pleasing, tangible displays that change subtly in order to deliver information that is non critical to the user, where the display’s information can move between the periphery and the center of the user’s attention (Pousman & Stasko, 2006).

Overall the domain is wide-ranging with steams of research focusing on the design, creation and evaluation of such displays. Numerous fields of study intersect in the design of Ambient Information Systems and these include Ubiquitous Computing, Information Decoration and Calm Computing.

Despite the many implementations of such technologies through the literature, it was found that the majority of Ambient Information Systems use the medium of light typically in the form of an LCD display utilising two-dimensional graphic visualisations in order to deliver information to the user.

In terms of the physical form that Ambient Information Systems typically utilise it was discovered that the displays in the literature typically fall under any of the two physical categories that were defined namely, tangible Ambient Information Systems and screen based Ambient Information Systems.

The typical motivations for developing Ambient Information Systems include information awareness, encouraging behaviour change and communication. However, some displays provide no distinct business motivation for development and the intent seems more personal or artistic in nature.

Various taxonomies or design dimensions for Ambient Information Systems have been suggested. However, there is no uniform standard and while the different taxonomies have many common elements all provide slightly different emphasis regarding the key features of such displays. Like the dimensions that define an Ambient Information System, the evaluation methods as well as the evaluation attributes that are used to measure the effectiveness of such displays vary. The domain as a whole could benefit from more standardisation in relation to design dimensions and evaluation approaches. Indeed many previous Ambient Information Systems have not been evaluated.

Overall research opportunities exist particularly in relation to the expansion of current taxonomies, evaluation methods and the exploration of new media representations. For example, one currently under utilised medium is the use of three-dimensional graphics, which is explored as part of this research. The research methodology that was utalised to investigate the use of three-dimensional graphics and the other dimensions of the research question are discussed next in chapter three.

Chapter 3

Research Methodology

This chapter explains and justifies the research design and methods that were used to implement and evaluate WaveWatch, a purpose built Ambient Information System. The intention of this research was to better understand the domain of Ambient Displays through the creation and evaluation of a novel Informative Art style display.

Chapter three consists of four sections that explain the research methodology that was utilised for this research. Firstly a review of the problems that the research is investigating and the questions that the research is aiming to answer are discussed. Next a number of contrasting research designs and methodologies are considered in relation to the current methodologies utilised in the domain. Using this knowledge, the method that was chosen for this research is explained and justified.

3.1 – Research Question

The research question of this research is:

> *What is the feasibility and effectiveness of developing an Ambient Information System that uses a 3D wave metaphor for displaying real-time web traffic data?*

In aiming to expand the domain of Ambient Information Systems, the research question addresses several areas that have not yet been explored, as well as those that require further investigation. More specifically the research investigates the feasibility and effectiveness of a novel ocean wave metaphor for visualizing temporal patterns in real time information. It also investigates the use of three-dimensional graphics to render the scenes on an Ambient Information System.

The research also reconsiders some areas of Ambient Information Systems that still require further investigation. Namely this concerns the under utilized design dimensions of such displays that attempt to balance aesthetic qualities with information relevance. The work also extends previous knowledge related to the intrusive in-situ evaluation of such systems.

In the following section, each of these intentions of the research are reviewed.

3.1.1 - Use of an Ocean Wave Metaphor

The WaveWatch Ambient Information System intends to utilise a unique metaphor, mapping the dynamics of web traffic to the dynamics of ocean waves. The intention is to assist in the recognition of temporal changes in web traffic activity by the changing activity of an ocean wave. Thus this research investigates the feasibility and effectiveness of this visualisation mapping as the primary information source on an Ambient Information System.

While there have been several Ambient Information Systems that have used an ocean or a beach for the aesthetics of the display (Miller & Stasko, 2001) WaveWatch is unique in that it utilises the dynamics of an ocean in order to visualise a real time information source. Investigated are the technical feasibility of creating such a real-time wave visualisation as well as the effectiveness of the ocean wave dynamics as a *glancable* metaphor, that is to convey peripheral information as required for use in an Ambient Information System.

3.1.2 - The use of three-dimensional graphics

As observed in chapter two, the majority of Ambient Information Systems in the literature utilise traditional screen-based two dimensional graphics or physical movement of sculptural objects for information transmission. This research aims to explore the novel use of three-dimensional graphics on a two-dimensional screen to display peripheral information.

The investigation into the use of three dimensional graphics is intended to investigate both the technical feasibility of utilising three-dimensional graphics, as well as the effectiveness of such a visualisation method for use in an Ambient Display. Both of these areas are yet to be fully investigated in the domain of Ambient Information Systems.

3.1.3 - Explore the proposed Aesthetic Awareness Display

As discussed in chapter two the proposed *Aesthetic Awareness Display* design pattern is utilised far less than the other design types identified by Pousman & Stasko (Pousman & Stasko, 2006). This research aims to further investigate this under utilised design type by considering the development and deployment of an Ambient Information System (WaveWatch) that embodies the key design features of this specific design pattern. *Aesthetic Awareness Displays* are characterised through the use of few information sources, high levels of aesthetic emphasis and the use metaphors for information representation.

The intention is to implement a representative display using these design features and then to evaluate its utility in a real work place.

3.1.4 - Build upon existing knowledge related to evaluation

As discussed in chapter two there are some difficulties in evaluating the utility of Ambient Information Systems due to the peripheral nature of the technology. This research aims to expand the existing knowledge related to the evaluation of Ambient Information Systems through an in situ evaluation of the WaveWatch display.

Next, considerations required for the overall research design (section 3.2, section 3.3) and selected research methods (section 3.4, section 3.5) are discussed.

3.2 – Research Design

Bryman and Bell define a research design as being the framework used to collect and analyse data for research purposes (Bryman & Bell, 2011). The relevance of one research design in comparison to another can be decided upon when reviewing a range of dimensions that inform the research process (Bryman & Bell, 2011). These dimensions include the connection between the research variables, the generalisation of these variables, understanding the meaning and context of the behaviour being studied, the importance of time in relation to the phenomena and any interconnections being observed (Bryman & Bell, 2011).

Broadly speaking there are three criteria that should be incorporated into the research design of a research project. Bryman and Bell define these three criteria as being reliability, replication and validity (Bryman & Bell, 2011). Reliability describes the ability of a research design to produce consistent results if the study is repeated (Bryman & Bell, 2011). Replication describes the ability of a specific research design to be repeated in future investigations. Validity is described by Bryman & Bell as the level of integrity in relation to the conclusions which were ascertained through the use of a particular research design (Bryman & Bell, 2011).

In terms of choice there are a number of research designs that could have been used to investigate the proposed research question. Section 3.2.1 investigates a range of these designs and assesses the appropriateness of each in relation to the research questions of interest in this study.

3.2.1 – Choice of Research Design

There are a number of different broad research designs, including Classic Experimental Design, Laboratory based design, Cross-Sectional design and Case Study designs that can be utilised in the research process. In this section, each of these design types are examined and evaluated in the context of the proposed research question. The reasons for the selected research design in this study are also explained.

3.2.1.1 – Classic Experimental Design

The research method known as *Classic Experimental Design* is a method where two test groups are formed for the purpose of experimentally manipulating an independent variable (Bryman & Bell, 2011) and measuring the subsequent effect on a dependent variable. One group typically referred to as the control group and the other referred to as the experimental group are both given a unique independent variable. The dependent variable is then observed, or measured, in relation to each group in order to try and determine the effect of the independent variable.

The medical domain commonly uses this type of research, for example, a Classic Experimental Design could be used to test the effectiveness of a medication, where two groups of participants are selected for testing and evaluation purposes. For example, if the efficiency of Vitamin C was being evaluated one group could be asked to take a Vitamin C supplement each day and the other group asked to take a placebo sugar pill each day. The use, or not, of Vitamin C would be considered the independent variable. The effect or dependent measure might be a measure of health, for example, the number of sick days experienced by individuals during the period of the experiment. In following this process the effectiveness of the supplement could be evaluated.

While the use of Classic Experimental Design does seem to be more suited to the evaluation of medicines rather than technology, similar research designs have been used to evaluate the performance of Ambient Information Systems. One example that utilised a research method similar to that of Classic Experimental Design was an evaluation carried out on the MoveLamp Ambient Information System (Fortmann, Stratmann, Boll, Poppinga & Heuten, 2013).

In evaluating the MoveLamp ten participants took part in a study that aimed to assess the motivational influence of a display that visualised the number of steps taken by the user. The MoveLamp functioned through the use of a mobile phone with a pedometer application installed. The phone would track the user's steps and then update an Ambient Display depending on the number of steps they had taken. As a control test the participants were asked to just carry the mobile phone. This independent variable was manipulated when the MoveLamp was deployed. The results before and after the MoveLamp was installed were analysed.

As seen through the MoveLamp study a Classic Experimental Design can be successfully used to evaluate an Ambient Information System, but this method was not chosen for the proposed research. This decision was influenced through the need of a Classic Experimental Design to either have two groups of experiment participants or the modification of one or more experimental variables. Each of these factors are not suited to the proposed research question where a comparison between variables or states is not required to fully investigate the question at hand. A simpler observation of in-situ phenomena is better suited to address the proposed question, which focuses on determining the utility of an Ambient Information System in a real life situation.

While the research design utilised for the evaluation of the MoveLamp does hold a likeness to the features of Classic Experimental Design it is also similar to a comparable research design type *The Laboratory Experiment.*

3.2.1.2 - The Laboratory Experiment

A laboratory experiment is similar to that of a Classic Experiment Design but differs in that the experiment itself is conducted within a controlled laboratory environment. Performing research within a controlled environment brings the advantage of a higher level of reliability in terms of how any independent variables are manipulated. By controlling the exact conditions under which the experiment is conducted there is a higher likelihood that results can be replicated through simple means (Bryman & Bell, 2011).

Despite this advantage of the laboratory experiment this design type was ultimately discounted for the proposed research, as it is important to evaluate Ambient Information Systems in a work or public environment due to their peripheral and ubiquitous nature. This is related to the aim of our own research question that seeks to evaluate the WaveWatch Ambient Information System in situ, namely in an office work environment. This precludes the Laboratory Experiment as an option in this research study.

By the very nature of Ambient Information Systems they are intended to operate in a ubiquitous fashion within ones environment, a feature that is difficult to replicate in a laboratory experiment. Not surprisingly, the use of laboratory experiments to evaluate the utility of Ambient Information Systems is rare and the type of intrusive in-situ evaluations selected for this study are more common. Although challenges do exist in researching Ambient Information Systems within a laboratory environment there are some examples in the literature that use such a research design. Typically, these involve a more controlled manipulation of a single design feature.

One notable example evaluates the use of various types of peripheral movement for generating awareness in Ambient Information Systems (McCrickard, Catrambone & Stasko, 2001). McCrickard, Catrambone & Stasko performed a laboratory experiment in order to evaluate the effectiveness of different types of animation in the periphery for purposes of information transmission (McCrickard, Catrambone & Stasko, 2001). The experiment itself consisted of a number of participants in a laboratory environment who were asked to complete a series of browsing tasks while also being encouraged to gather information from an Ambient Display.

While the research of McCrickard, Catrambone & Stasko displays the possibility to evaluate design elements of Ambient Information Systems through a laboratory experiment, this approach was not considered optimal for this study due to our motivation to evaluate an Ambient Information System in a real life work place environment. Due to this reason, research designs beyond the classic experiment and the laboratory experiment were investigated in order to find the most befitting research design for the question at hand.

3.2.1.3 - Cross-sectional Design

Another research design that was considered early on in the research design process was the Cross-sectional Design. A Cross-sectional design is defined by Bryman & Bell as being characterised through the collection of data from multiple cases, typically in connection to two or more variables (Bryman & Bell, 2011). The Cross-sectional design could be utilised for the evaluation of Ambient Information Systems but was considered to be too wide in scope for the time frame of the proposed research.

There are examples of research in the domain of Ambient Information Systems that have applied a Cross-sectional design. One such example that uses a similar method is the research of Rogers, Hazlewood, Marshall, Dalton & Hertrich (2010). In aiming to determine how individuals reacted to and reflected on Ambient Information Systems, this project centred around the development and deployment of three separate Ambient Displays. Each separate display acted as a case in itself and overall the intention was to determine how individuals perceived different types of Ambient Information Systems. The Ambient Displays "Follow the lights, "The Clouds" and "The History" were implemented into an in-situ environment and then evaluated (Rogers, Hazlewood, Marshall, Dalton & Hertrich, 2010).

A similar approach is taken for the proposed research, but since the research does not focus on comparing different Ambient Display types, a single case is utilised. A research design comprising of a single case is referred to as a Case Study Design, this design type is discussed further in section 3.2.1.4.

3.2.1.4 - Case Study Design

The Case Study research design is described by Bryman & Bell as an in-depth analysis of a single case (Bryman & Bell, 2011). A single case typically observes an organisation, a location, a person, a process or a single significant event (Bryman & Bell, 2011). Like the other research designs described, Case Studies are better suited to particular research questions over others. In this case, the Case Study design is suitable when “how” or “why” research questions are being asked, where there is little control over the experiment's events and when the context of the research is related to phenomena in a real life situation (Yin, 1989).

Cited frequently in the literature surrounding the Case Study Research design is the work of both Yin (2003) and Stake (1995). Each of these authors describe variations of the case study method (Yin, 2003; Stake, 1995), further categorising this approach by defining discrete types of case studies. Yin contrasts *explanatory*, *exploratory* and *descriptive* case studies (2003) while Stake differentiates *intrinsic*, *instrumental* or *collective* case studies (1995). Both authors suggest that once a case study research design has been decided upon, the specific type of case study should be identified (Baxter & Jack, 2008). Each of the case study types described by Yin (Yin, 2003) and Stake (Stake, 1995) are now described and the most appropriate case study type utilised for the proposed research question identified.

As previously noted Yin categorises *explanatory, exploratory and descriptive* case studies (2003). As defined by Yin, the Explanatory Case Study would be utilised when a researcher is seeking to explain the presumed links that exists between phenomena in the real world (Yin, 2003). Explanatory case studies are typically used to explore cause and effect relationships, when observing how events initially occur and how they ultimately effect or contribute to a particular outcome or phenomena (Hancock & Algozzine, 2006). For example, an explanatory Case Study may seek to explore the relationship between a student's economic background and their academic performance.

The second case study type defined by Yin is the Exploratory Case Study. An Exploratory Case Study is used to investigate a research problem where a clear set of results is yet to be defined (Yin, 2003). Explanatory designs can help in the formation of research questions and can often lead to future investigation in the form of more specific fieldwork (Hancock & Algozzine, 2006).

A Descriptive Case Study is the third category of case study proposed by Yin. Such studies aim to observe and analyse a real life situation or phenomena (Yin, 2003). This type of case study involves a detailed description of the subject of interest.

By contrast Stake differentiates *intrinsic*, *instrumental* or *collective* case studies (1995). The Intrinsic Case Study Design (Stake, 1995) can be used by the researcher to investigate a particular organisation, event, or group (Hancock & Algozzine, 2006). It is suggested by Stake that the researcher should have a genuine interest in the case with the aim to gain knowledge in relation to the phenomenon at hand rather than being motivated to create new theories (Stake, 1995).

Alternatively, Stake's Instrumental Case Study does aim to provide insights into a phenomenon as well as refine current theory (Stake, 1995). This case study type can be used to help answer a theoretical research question (Hancock & Algozzine, 2006).

Stake's third type of Case Study, the Collective Case Study aims to create new knowledge as well as enhance current theories through the undertaking of multiple case studies. Typically, these case studies take the form of an Instrumental Case Study (Hancock & Algozzine, 2006).

3.2.1.5 - Summary

Along with other prominent research designs, the Case Study research design and its subtypes as defined by Stake and Yin (2003) have been explored. It has been found that the Case Study method is a powerful tool for observing and analysing complex real life phenomena. An Instrumental Case Study has been chosen for the proposed research. The reasoning behind this choice is discussed in section 3.3.

3.3 Choice of an Instrumental Case Study Design

After considering a number of research designs, an Instrumental Case Study research approach was selected. This choice was driven by two main factors, firstly the intention of the research question to observe an in-situ phenomenon and secondly through the motivations described by Yin for choosing a case study research design. Each of these factors are discussed below.

A major part of the research question as discussed in section 3.1.4 notes the intention of the research to evaluate the effectiveness and utility of an Ambient Information System that utilises an ocean wave metaphor within an office environment.

The power of a case study in comparison to a more traditional laboratory or classical experiment is the in-situ nature of the research method, where a large focus is placed on observing and analysing a phenomenon in the real world (Yin, 1989). As we intend to evaluate the display we develop in a real world setting the case study approach is deemed appropriate. In addition to this criterion further positive reasons for choosing a case study design are outlined by Yin and these are discussed in relation to our own study in the next section.

As outlined previously, the Case Study research design is well-suited to answering research questions that revolve around “how” or ‘why” questions and where there is little control over the nature of possible experimental events or when the context of the research is related to phenomena in a real life situation (Yin, 1989). Each of these factors are relevant in evaluating Ambient Information Systems.

Each of these elements described by Yin apply to the proposed research question with differing levels of importance. Most notable in relation to our proposed research question are the “how” and the context of real life phenomena as described by Yin. Indeed these elements are notable as they are fundamental parts of the proposed research question. For example, the research aims to observe “how” an Ambient Information System that utilises a three dimensional wave metaphor to visualise web traffic will perform in a real life situation. This fact informed our decision to choose a case study research design.

In addition to the main decision to use a case study research design, a choice was made that the research at best fits the Instrumental case study type as described by Stake (Stake, 1995). The main reason behind this was influenced around Stake’s description where emphasis is put on discovering knowledge around a real life phenomenon as well as refining current theory (Stake, 1995). Each of these elements are prominent in the proposed research question where emphasis is put on both information discovery and the expansion of current knowledge related to Ambient Information Systems.

In summary, the decision to choose an Instrumental Case Study research design was informed by the intention of the research question to observe the in-situ phenomenon of a highly-contextualised real-world display.

With a decision made around a research design, a suitable research method had to be chosen in order to facilitate the collection of data. The choice of a suitable research method is discussed in section 3.4.

3.4 – Research Method

A research method is described simply by Bryman & Bell as being a method of collecting data for research purposes (Bryman & Bell, 2011). Several data collection methods were considered for the proposed research including structured interviews, structured observation and self-completion questionnaires. Each of these research methods are now discussed along with the research method chosen for the WaveWatch study.

3.4.1 – Structured Interview

Structured interviews are a common research method for collecting both quantitative and qualitative data (Bryman & Bell, 2011). A structured interview typically comprises of an interviewer who interviews individuals in a structured manner, where interview related variables are made to be constant in order to maintain consistency (Bryman & Bell, 2011). For this reason, close ended questions are usually asked of the interviewee by the interviewer (Bryman & Bell, 2011).

Although the Structured Interview can be a relatively simple and powerful data collection tool, the method does suffer from several issues that can have a negative effect on the validity of a research project. These issues are often related to the nature of the method itself where interviewer variability, the attributes of the interviewer and response bias can reduce the reliability and validity of the method (Bryman & Bell, 2011).

3.4.2 – Self-Completion Questionnaire

A Self-Completion Questionnaire can take on many forms such as a postal questionnaire or an online questionnaire (Bryman & Bell, 2011). As the name suggests a Self-Completion Questionnaire is completed by participants themselves without the need for prompting or probing from the researcher (Bryman & Bell, 2011). The Self-Completion Questionnaire holds a number of advantages over the Structured Interview method in that a Self-Completion Questionnaire is both cheaper and quicker to administer and a free from interviewer based issues such as bias and variability (Bryman & Bell, 2011).

The Self-Completion questionnaire does hold a number of advantages over the Structured interview method, where a Self-Completion Questionnaire is typically free from the effects of the interviewer who can often reduce the reliability and validity of a Structured interview (Bryman & Bell, 2011).

Although the Self-Completion Questionnaire does hold its advantages over the Structured Interview Method, it still has disadvantages when both methods are compared. Namely, in performing a Self-Completion Questionnaire the opportunity to prompt or probe a respondent is absent, the number of open ended questions has to be kept low due to respondent fatigue, response rates can be low and the respondents can easily decide to not answer all of the questions (Bryman & Bell, 2011).

3.4.3 – Structured Observation

Structured Observation is a research method that can be used to observe the behaviour of individuals (Bryman & Bell, 2011). Direct observation is utilised by the researcher in order to observe and then analyse the behaviour of a participant or participants. Although Structured Observation is a powerful tool for observing behaviour, the method does have several issues that have seen it become less used in recent years (Bryman & Bell, 2011). Such issues include the influence of the interviewer and gaps between stated and actual behaviour (Bryman & Bell, 2011).

Like the Structured Interview and Self Completion Questionnaire methods, the Structured Observation method does have its shortcomings. Bryman & Bell note that the method does have issues with both Reliability and Validity (Bryman & Bell, 2011), where if multiple observers are used consistency issues can occur, participants may change their behaviour if they know they are being observed and variability over time can skew results.

3.4.4 – Summary

After observing the utility of the Structured Interview, Self-Completion Questionnaire and the Structured Observation method, a decision was made to utilise a Self-Completion Questionnaire as the primary research method for this research.

A Structured Interview was found to be inappropriate due to the time to complete such a method, the effort required in order to interview a sufficient number of individuals to ensure an appropriate sample size and the possibility of introduced bias from the interviewer. Like the Structured Interview method, a Structured Observation was not chosen due to the potential for bias as well as the unsuitability of a Structured Observation method in relation to the research question, where a longer in-situ evaluation in required.

In summary the Self-Completion Questionnaire was chosen for this project due to its ease of implementation, ability to be undertaken by the participants themselves, ability to be easily conducted in an online environment and its capacity to be free from interviewer bias. The implementation of the Case Study research design and the Self-Completion Questionnaire method are discussed in section 3.5.

3.5 – Implementation of research methods

A combination of a Case Study research design and a Self-Completion Survey method were used for the proposed research. Specifically, the research methodology is comprised of two parts, the implementation of an Ambient Information System into an in-situ environment to try and assess the technical, design, development and deployment issues of implementing such a display and a follow up Self-Completion Questionnaire designed for evaluating the user experience and overall efficacy of the actual display content.

A major portion of the research question aims to determine the feasibility of developing and deploying a display. The technical issues were collected by completing a research diary and reflecting on the design process throughout the research project. The intention was to highlight key issues that might need to be addressed in further more targeted research studies.

The WaveWatch Ambient Information System was also created in order to determine the effectiveness of using three dimensional graphics and an ocean wave metaphor for dynamic data visualisation on an Ambient Information System. To evaluate this aspect of the display, a Self-Completion Survey was created. More details around the case study and the formulation of a Self-Completion Questionnaire are now discussed.

The WaveWatch display was designed and developed using an iterative prototyping approach in collaboration with staff from the Marketing and Public Relations (M&PR) office at The University of Newcastle, Australia. The data chosen for display was related to the web traffic of a webpage of interest to this working group.

This development occurred over a two month period where a range of design options were considered. After developing the final design it was implemented and further tested for seamless real-time technical operation. After this testing period the display was deployed for a two week evaluation period in the Marketing and Public Relations office, which may be described as a typical corporate office environment. After the two week evaluation, the employees of the M&PR office were asked to complete a Self-Completion Questionnaire in relation to their experience with the WaveWatch. Participation was entirely voluntary and had been approved by The University of Newcastle's Research Ethics Committee (Approval No. H-2015-0213).

The Self-Completion Questionnaire was administered in the form of an online survey (See Appendix A). The online survey was formulated through the use of two previously documented technology evaluation methods, one tailored specifically for the evaluation of Ambient Information Systems (Mankoff et al., 2003) and another more generic system evaluation method (Davis, 1989). Each of these evaluation methods are discussed next.

The first section of the online survey was created through forming a survey version of the Heuristic evaluation of Ambient displays, as described by Mankoff (Mankoff et al., 2003). Describing a set of techniques to evaluate the usability and effectiveness of Ambient Displays, Mankoff formulated a set of modified Heuristics specifically for the domain of Ambient Information Systems. Mankoff's Ambient Display Heuristics are described in table 3.1

Table 3.1 – Key heuristics for Mankoff's Ambient Display evaluation. Adapted from (Mankoff et al., 2003).

#	Heuristic	Description
1	Useful and relevant information	The information on the Ambient Display should be useful, and relevant to the setting in which the display will be implemented (Mankoff et al., 2003).
2	"Peripherality" of display	The display should not distract the user unless the display requires the attention of the user (Mankoff et al., 2003).
3	Match between design of ambient display and environments	An Ambient Display should be noticed by a user due to its transition in data visualisations, not by it clashing with its environment (Mankoff et al., 2003).
4	Sufficient information design	The display should not display too much information, but display "just enough" (Mankoff et al., 2003).
5	Consistent and intuitive mapping	Cognitive load should be minimal to interpret the data presented on the display (Mankoff et al., 2003).
6	Easy transition to more in-depth information	If the display is capable of displaying both top level and more in-depth information, it should be easy for the user to interpret this information (Mankoff et al., 2003).

7	Visibility of state	The states displayed on an Ambient Display should be easily visible to the user (Mankoff et al., 2003).
8	Aesthetic and Pleasing Design	The display should be aesthetically pleasing (Mankoff et al., 2003).

In designing the Self-Completion questionnaire each of Mankoff's Heuristics were converted into close ended questions to simplify the collection of Heuristic data through an online Survey. Through the formulation of specific questions from Mankoff's Heuristics, a Heuristic online survey specifically designed for evaluating an Ambient Information System was created.

In addition to Mankoff's Heuristics a second standardised survey from the domain of Information Technology was utilised in order to evaluate the utility of the Ambient Information System. The second half of the online survey comprised of 14 questions adapted from the *Perceived Usefulness and Ease of Use* evaluation survey (Davis, 1989). Traditionally used for evaluating computer applications and new technology, Davis describes a set of criteria for measuring the perceived usefulness and ease of use of a particular information technology system (Davis, 1989).

Davis cites two reasons for evaluating systems upon the axes of usefulness and ease of use, both of which are related to the typical reasons why individuals reject a particular technology. For example, users tend to accept a technology if there is a "Perceived Usefulness", in that the technology is perceived to have a positive effect on their job performance (Davis, 1989). The second criterion, "Ease of Use", is described as the degree to which an individual perceives a system to be free of additional personal effort to adopt (Davis, 1989).

Although the Perceived Usefulness and Ease of use criteria as outlined by Davis (Davis, 1989) have not been previously utilised for evaluating the performance of an Ambient Information System, it is a widespread survey instrument in the domain of Information Technology. Davis' approach was adapted for this research due to its appropriateness to our research question that aims to determine the perceived utility of an Ambient Information System within a real life office setting.

The Perceived Usefulness and Ease of Use criteria are a good data collection tool for such a question, due to the criteria's focus on determining perceived usefulness of a system, which is ultimately what this research aims to do in relation to an Ambient Information System. A further reason for adopting Davis' criteria is that the survey questions are already applicable to Ambient Information Systems due to their general focus on new technology.

Both Mankoff's Heuristics and Davis' Perceived Usefulness and Ease of Use criteria were formed into a single Self-Completion Questionnaire. The full survey that was used for the evaluation of WaveWatch is provided in Appendix A along with the research's approved Information Participation Statement.

3.6 - Conclusions

In summary the proposed research aims to investigate the feasibility and effectiveness of an Ambient Information System that uses a three dimensional wave metaphor for displaying real-time web traffic data. Specifically, the research investigates:

- The feasibility and effectiveness of a novel ocean wave metaphor for visualizing real -time information;
- The use of three dimensional graphics for a real-time Ambient Information System and;
- The efficiency of the Ambient Display as assessed through an intrusive in-situ evaluation.

Discussed in chapter three were a number of research designs and methods that were considered in relation to the proposed research. After considering a number of research designs and methods an Instrumental case study was chosen due to its suitability in relation to the research question that aims to evaluate an Ambient Information System in an in-situ environment. As a data collection method, a Self-Completion Questionnaire was selected due to the method's ease of implementation and power to gather the data required for the proposed research.

A major part of the research question as discussed in chapter three is the desire to investigate the technical feasibility of creating an Ambient Information System that utilises a three dimensional ocean wave for data visualisation. Chapter four discusses the iterative development that was undertaken for designing and creating the WaveWatch Ambient Information System, reporting on technical issues that were identified during the design and development of the display.

Chapter 4

WaveWatch: Motivations, Design and Technical Details

4.1 Introduction

This chapter introduces the technical portion of the WaveWatch case study and reports on the general research findings that were ascertained during the display's design and development process. WaveWatch is intended as an Ambient Information System that visualises real-time web traffic data through the use of an ocean wave metaphor. WaveWatch is designed to meet the *Aesthetic Awareness Display* design pattern as discussed in Chapter 2. This chapter discusses the design and development of the WaveWatch highlighting issues related to the technical implementation and deployment of the display. The motivations and business case for developing the WaveWatch are also discussed.

Another intention of the WaveWatch display was to utilise high definition 3D rendered graphics in order to deliver information to the user. As noted in chapter 2, there are few examples of Ambient Displays that use such a visualisation method. The use of 3D graphics is advantageous as it introduces more flexibility around the design of the display. However, it also has the potential to make the design and implementation process more complex and time consuming. Implementation issues around the production of the 3D graphics for the WaveWatch are also discussed in this chapter.

4.2 Business Motivation

Being aware of website traffic is important for any marketing team or webmaster in order to gauge the performance and engagement of a website. Visibility of such data is traditionally gained through the use of a tool such as Google Analytics (Google.com, 2015). These types of analytical tools are powerful and well suited to the detailed study of webpage activity. However, to use such a tool the user is required to actively engage and interact with a computer system to try and gain an understanding of changing web traffic volumes.

WaveWatch aims to move this secondary monitoring task to the user's periphery without distracting them from their other work activities. Through placing real time information into the user's environment WaveWatch attempts to peripheralise useful information that is not immediately visible or would otherwise require effort from the user to access. The display does not try to replace web analytics tools such as Google Analytics (Google.com, 2015), instead it to attempts to raise awareness of a single metric through the use of a "glanceable" metaphor.

A key design feature of Ambient Information Systems is that they display useful information. For the WaveWatch display it is important that the display is dynamic and presents interesting changes in real time. Web Analytics as a data source is a good match for such an Ambient Information System, not only due to the fact that such data typically requires effort from a user to become visible but also due to the frequent updates and changes in web traffic volumes that can occur. This increases the dynamic potential of an Ambient Information System that utilises such a data source.

4.3 The WaveWatch Design Process

The WaveWatch is designed as a screen-based *Aesthetic Awareness Display*. WaveWatch visualises the dynamics of web traffic data in real time and in particular is intended to display the number of active users on a single webpage. The WaveWatch uses the changing intensity of an ocean to depict these dynamics. There were two main features that needed to be considered for the WaveWatch display, the aesthetics of the ocean scene and the various visualisation levels. Each of these parts were designed through an iterative process of designing, testing and evaluating prototypes (See figure 4.1). Each stage of the design process, the determination of requirements, the iterative prototyping process, the final in-situ deployment and usability evaluation are now discussed. During this discussion the various issues identified in the case study are also noted. In total three major iterations of the iterative prototyping stage were carried out before the final design was deployed and evaluated.

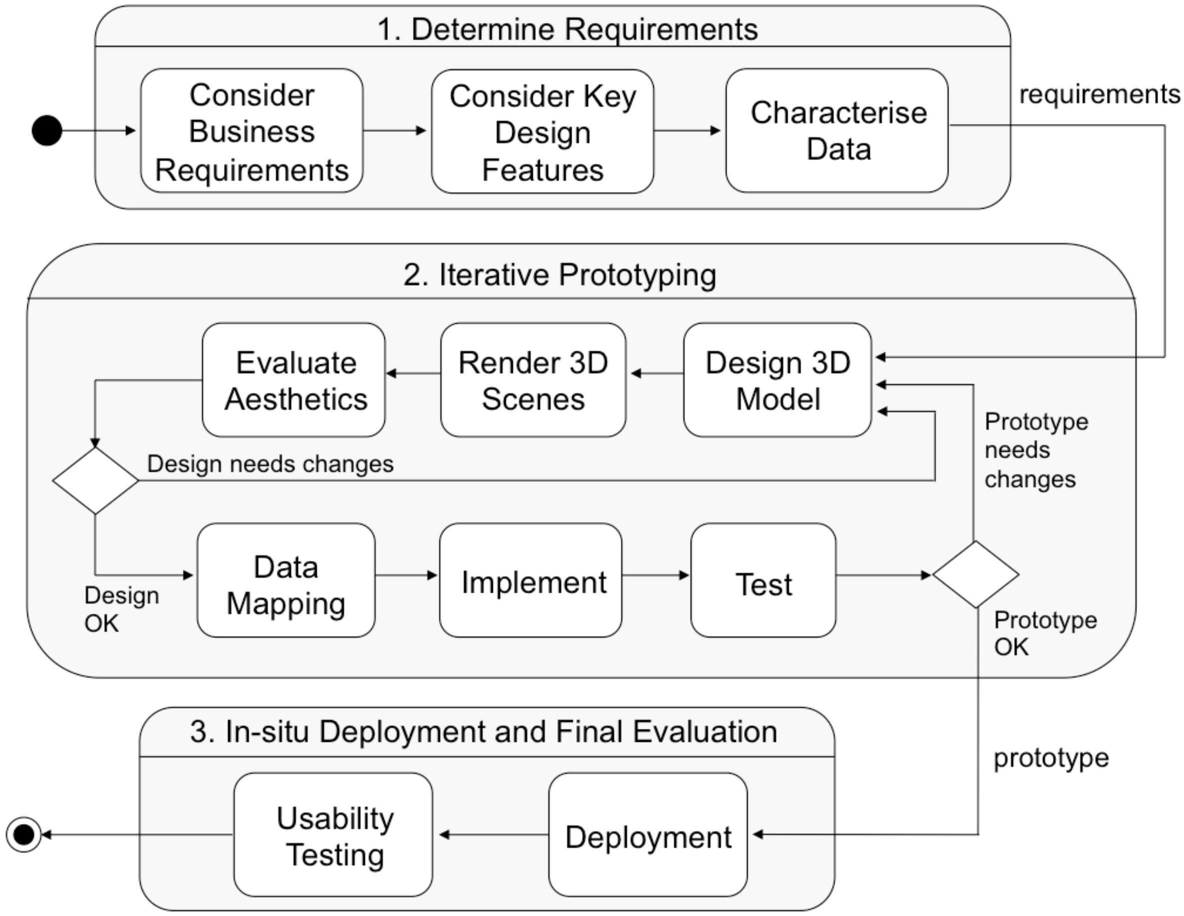


Figure 4.1 A UML diagram showing the design and development process

4.3.1 Consider Business Requirements

The WaveWatch prototype featured in this research was designed to display web traffic data within a specific office setting. The display was designed to operate within the Marketing and Public Relations department at The University of Newcastle, Australia and to display traffic levels related to a specific webpage of interest to this group. The display of relevant data to the proposed audience is an important design goal of such a display. To better understand any technical issues it was also considered important to deploy the display in a real world environment. As well as identifying realistic deployment issues, this in-situ approach was taken in order to help validate the final evaluation of the WaveWatch (discussed in chapter 5).

The Marketing and Public Relations (M&PR) department at The University of Newcastle is responsible for the University's corporate website (http://www.newcastle.edu.au). As part of M&PR's ongoing work they monitor the website's traffic to gauge user engagement and traffic volumes overall. Currently M&PR use the tool Google Analytics (Google.com, 2015) to monitor website traffic and to create web traffic reports.

The WaveWatch was specifically designed to compliment the reporting activities already undertaken by the M&PR team. Rather than being a replacement for the high level reports already created by the team, WaveWatch aimed to increase awareness in relation to the number of visitors to a popular webpage on The University's corporate website. By deploying the WaveWatch display into a highly visible area of the M&PR office the aim was to increase the collective awareness of web traffic volumes to the team.

In addition to usual traffic patterns, M&PR also perform marketing campaigns in an effort to drive traffic to specific parts of The University's website. Over time it was anticipated that the display could be particularly useful for monitoring performance in such targeted marketing campaigns to help gauge any increase of web traffic to intended sites. Thus if the WaveWatch is successful it is expected that the results of key marketing events could be monitored in a highly visible way on the WaveWatch display.

4.3.2 Consider Key Design Features

In order to explore the possibilities and utility of the proposed *Aesthetic Awareness Display* (as defined in Chapter 2), the overarching design goals of the display were aligned to the four key design features of this pattern. Each of these design features helped to inform the overall design and functionality of the display. These design features, and how they were addressed in WaveWatch, are discussed below.

1. Be a ubiquitous and calming display

The first of these goals is tightly linked to the concept of Calm Computing (Weiser & Brown, 1996). An overarching aim of the display was for it to be both non-alarming and to blend into the user's environment. During the design process we tried to ensure that the dynamics of the display were not distracting. This was to ensure the display stayed in the user's periphery, acting as a secondary source of information that did not unnecessarily divide their attention from their primary task.

2. Inform the user of a single metric through a *glanceable* metaphor

The second of these overall goals is related to the want to create a very simplistic display as to not overload the user with too much information. In the WaveWatch display this was achieved by designing discrete variations in the various levels of activity. It was also decided to display only a single aspect of data, namely the number of current active users on a single webpage.

3. Add additional useful information to the periphery.

In utilising another concept of Calm Computing (Weiser & Brown, 1996) the WaveWatch aimed to add additional useful information to a user's periphery. In terms of the WaveWatch the data displayed was very relevant to the workers in the area that the display was to be deployed. Namely the number of active users on a webpage that was the responsibility of a team of workers situated in the same office environment where display was deployed. While the WaveWatch was intended to be specific, it has also has been designed so it could be applied to a variety of scenarios by simply changing the display's dynamic data source.

4. Be highly aesthetic.

Following the concepts of Information Art (Redström, Skog & Hallnäs, 2000) it was decided that the display should be highly aesthetic in order to blend into it's environment and therefore become ubiquitous. This was achieved in the WaveWatch through an iterative design approach, where a of total three different iterations were carried out. The various designs are discussed in Section 4.3.4 along with notes on the aesthetic and implementation trade-offs that were considered. The final design is discussed in the section 4.5.

4.3.3 Characterise Data

An important consideration for the display requirements was to understand the range of values expected in the data. That is how many users might be expected and what kind of variations could be expected. The main design consideration that had to be made for the WaveWatch display was the number of intensity levels that would apply to the scene and the frequency to which these levels would change. Both of these design decisions were informed through a process of real-time data collection and analysis.

To study the typical number of users accessing the specific webpage to be visualised, web traffic data was collected for a period of seven days. A custom data scrapper was written for this process, where every minute the scrapper would use the Google Analytics live reporting API (Google Developers, 2015) to determine the number of active users on the webpage. This data was then stored in a SQL Server database (Microsoft.com, 2015). After a week of running the scrapper the data out of SQL Server was exported and plotted (see Figure 4.2, Figure 4.3).

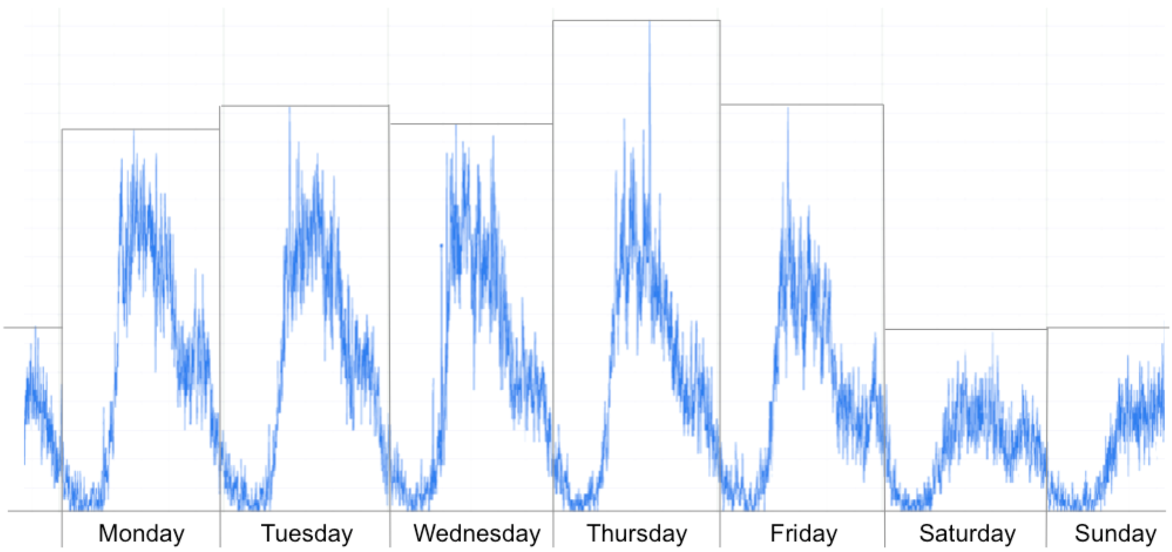


Figure 4.2 A plot of web traffic data showing typical changes in web traffic over a period of seven days.

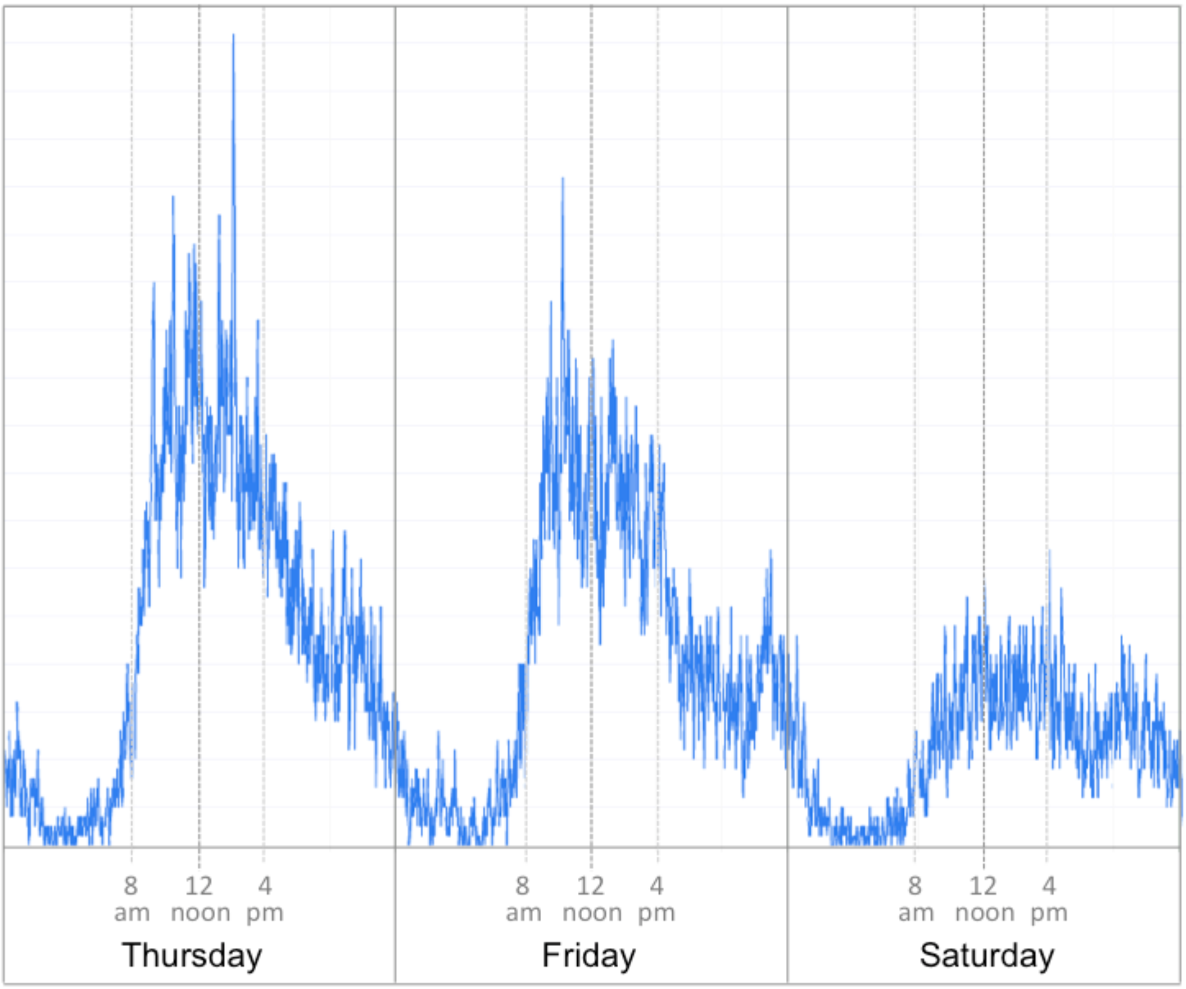


Figure 4.3 A plot of web traffic data showing typical changes in web traffic over 3 days.

When reviewing the data it was found that there seemed to be consistent temporal patterns that could be visualised. At quiet times such as post midnight and up until about 8am there were very few active users. This changed during normal work hours, that is between about 8am and 4pm, when it was common to see a large cluster of similar values (See Figure 4.3). It was expected that it would be during this day period that the Ambient Display would be most visible and so it would be desirable to make sure these smaller fluctuations would still be visible in the display. Without careful design the intensity levels of these smaller intraday changes in data would not be captured.

In an effort to create a display that was dynamic and interesting it was decided that the discrete intensity levels rather then being evenly distributed would change in scale to highlight the changes that occur around the typical intraday values (See Figure 4.4). That is, by grouping many intensity levels around the clustered traffic levels any intraday changes would be highlighted by noticeable dynamic changes in the ambient visualisation.

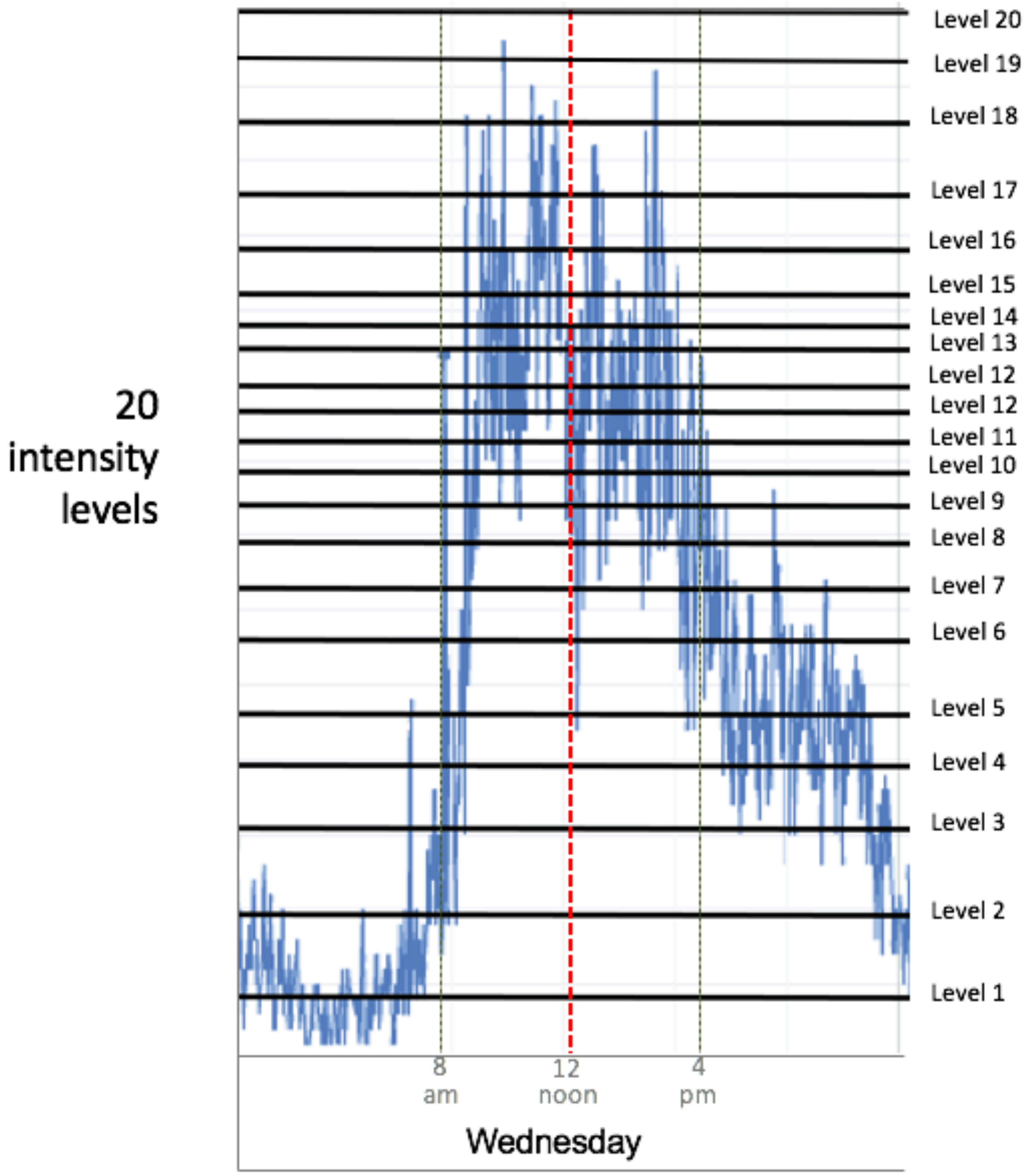


Figure 4.4 - Each of the 20 WaveWatch levels presented as a line on web traffic data. Note how the levels during normal work hours are more frequently distributed. This serves to highlight smaller intraday fluctuations in the number of active users.

4.3.4 Iterative Prototyping Process

During the iterative prototyping phases of the design process a number of different modes of visualisation were considered. Early on in the requirements phase it was decided that the display would explore the use of three dimensional graphics in order to deliver a visualisation. This visualisation method was chosen after reviewing previous literature and determining that this was a form of Ambient Media that was yet to be investigated in depth.

The intention of the iterative prototyping was to implement a functional Ambient Display with the most appropriate look and feel. The display needed to allow for 20 different levels of web activity to be distinguished. This was an approximate number of levels decided on by considering the character of the data (Section 4.3.3). The design was also required to meet the four key design goals, (Section 4.3.1) one of that was the development of a display that was subjectively judged to be aesthetically pleasing.

Many different representations were explored before the choice of the wave metaphor was decided on. Bouncing balls, balloons blowing up and shapes increasing in size were all considered but thought to be too abstract and to lack the necessary degree of engagement that would interest users. In one sense almost any natural metaphor could have been selected that showed some kind of discernable movement. However, the decision to use the natural metaphor of an ocean wave was not completely arbitrary. Anecdotally, it is not unusual for people to find themselves engaged in the activity of simply watching waves. Waves naturally seem to lend themselves to an aesthetic representation that is appreciated by a broad audience. Furthermore, the calming aspect of an ocean scene was considered to match well with the intentions of 'calm technology'.

More specifically, surfers typically engage in reading wave patterns, analysing the various dynamic qualities of waves in their quest to find the best surfing conditions. This suggests that there might also be a number of different opportunities to manipulate waves action in simple quantitative ways, such as in size and frequency. Thus it was feasible that a wave would allow for the required levels of intensity (~20) to be recognisable in the display by simply linking web activity with ocean activity and specific parameters such as wave frequency and wave size. Apart from such quantitatively interpreted patterns there also existed possible qualitative parameters such as the quality or consistency of waveforms that might be applied to the display. For example, variations in the data might be reflected in variations of the quality or perfection of the waveform itself.

Having decided on the broad design, namely a wave, the final scene composition was explored through three main design prototypes (See Figure 4.5, 4.6, 4.7). During each of these iterations various parts of the process were given more or less attention. In the first two iterations the focus was on the 3D modelling, scene rendering and assessing the aesthetic qualities of the scene. By the third prototyping phase, that is once the aesthetic qualities were considered appropriate, the focus shifted to the data mapping, implementation and prototype testing activities. This led to some further subtle refinement of the 3D Modelling to consider the transition between scenes and the adequate differentiation between the twenty data levels. In the following sections we discuss each step of the process in detail and describe the main refinements and design issues that were identified during the various iterations of the display.

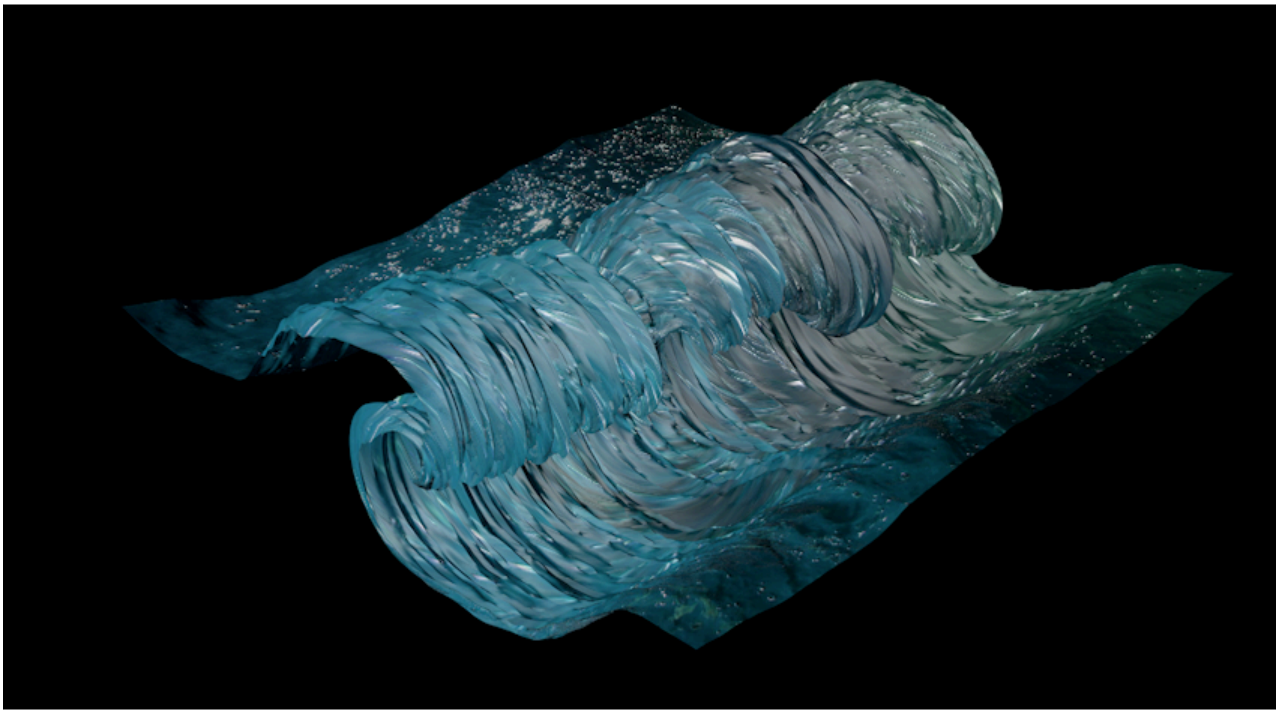


Figure 4.5 Prototype one of the WaveWatch display. A realistic turbulent ocean with a large wave is presented.

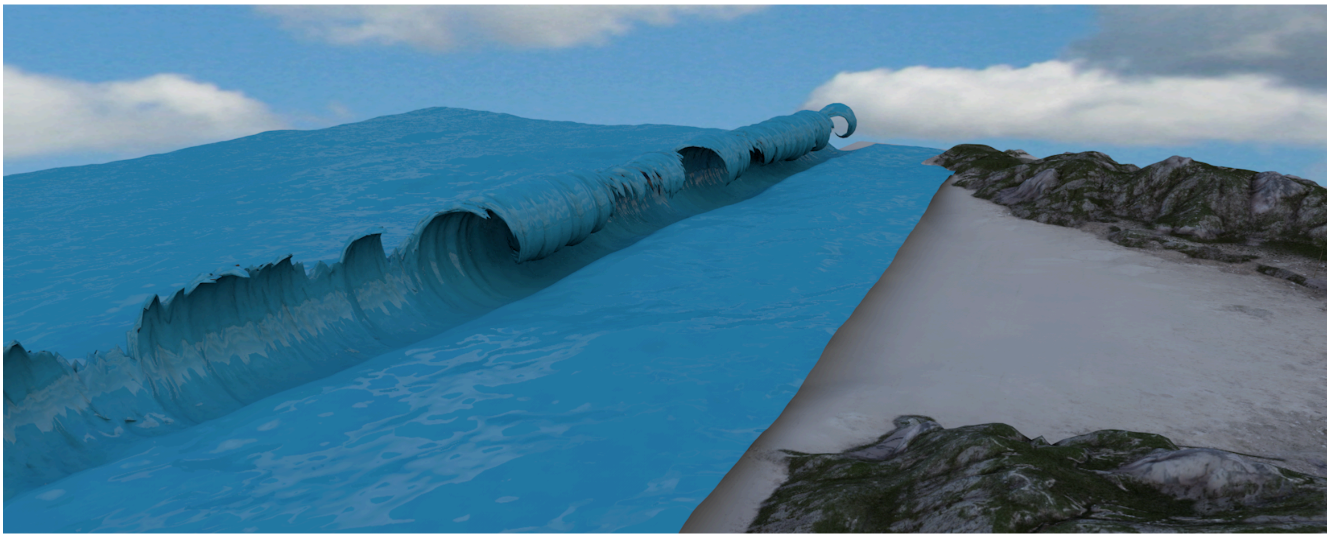


Figure 4.6 Prototype two of the WaveWatch display. A realistic beach scene is displayed featuring a large breaking wave.

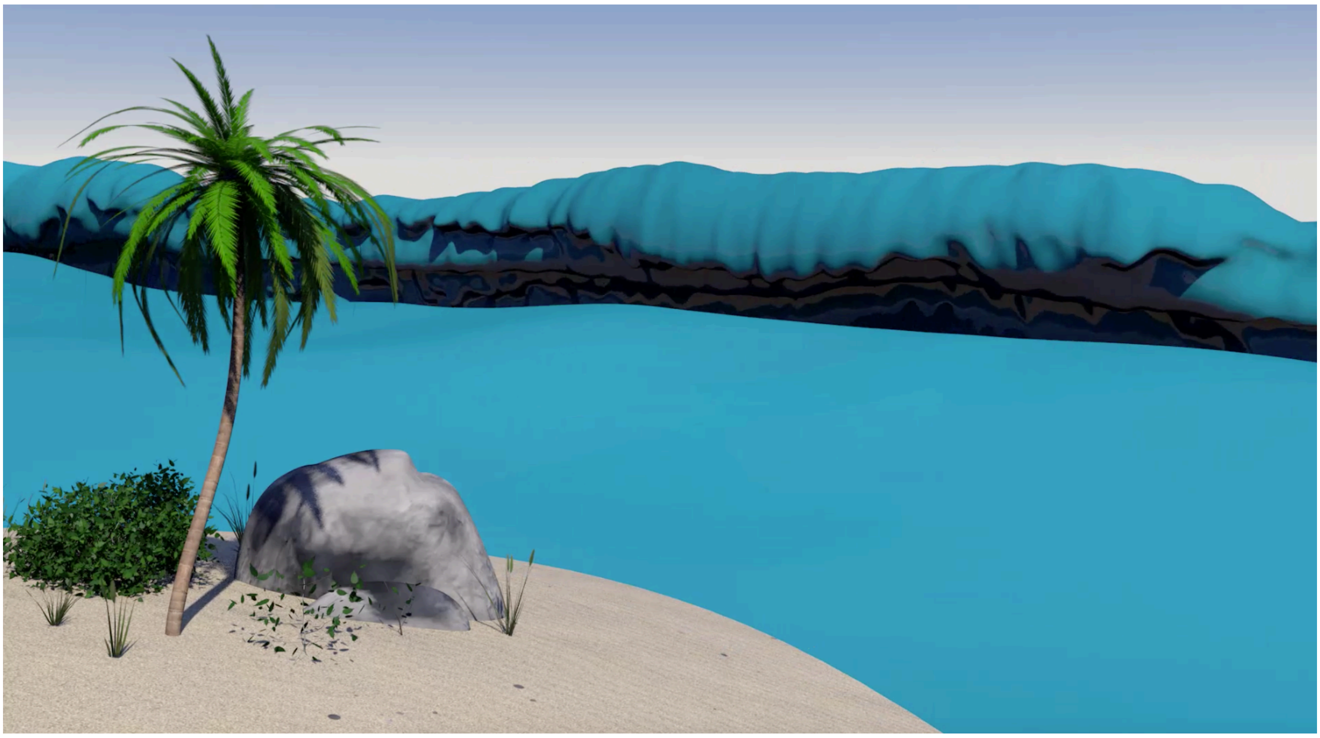


Figure 4.7 The final prototype of WaveWatch visualising web traffic through a large ocean wave.

4.3.5 Design 3D Model

The 3D wave models used for the WaveWatch prototypes were created using the software Cinema4D (Maxon.net, 2015). Cinema 4D is a flexible 3D graphics modelling tool that allows both the modelling and rendering of animated scenes. The background elements in the various prototypes such as the beach and palm tree, various rocks and shrubs were sourced as pre-existing models from Cinema4DDepot (C4Depot, 2015).

The animated ocean of the display was created through a combination of two tools in Cinema 4D. The first of these, the noise tool was used to create the ocean chop of the scene. All of the chop effects as seen in the WaveWatch prototype were created by applying a Displacer object to a plane and modifying its Noise Shader attributes. For all of the intensity levels, a Noise type of "Noise" was set, the other attributes of the Noise Shader are visible in figure 4.8. The "Height" attribute was modified on the Object Properties panel of the Displacer Object to change the height of the ocean's chop.

Table 4.1- Each of the Displacer Object/Noise Shader attributes for the WaveWatch intensity levels.

Intensity Level	Animation Speed (Noise Shader)	Object height (Displacer Object)
Level 1	0.7	0.7 cm
Level 2	0.7	0.957 cm
Level 3	0.8	1.1 cm
Level 4	0.8	1.20 cm
Level 5	0.9	1.35 cm
Level 6+	0.9	1.60 cm

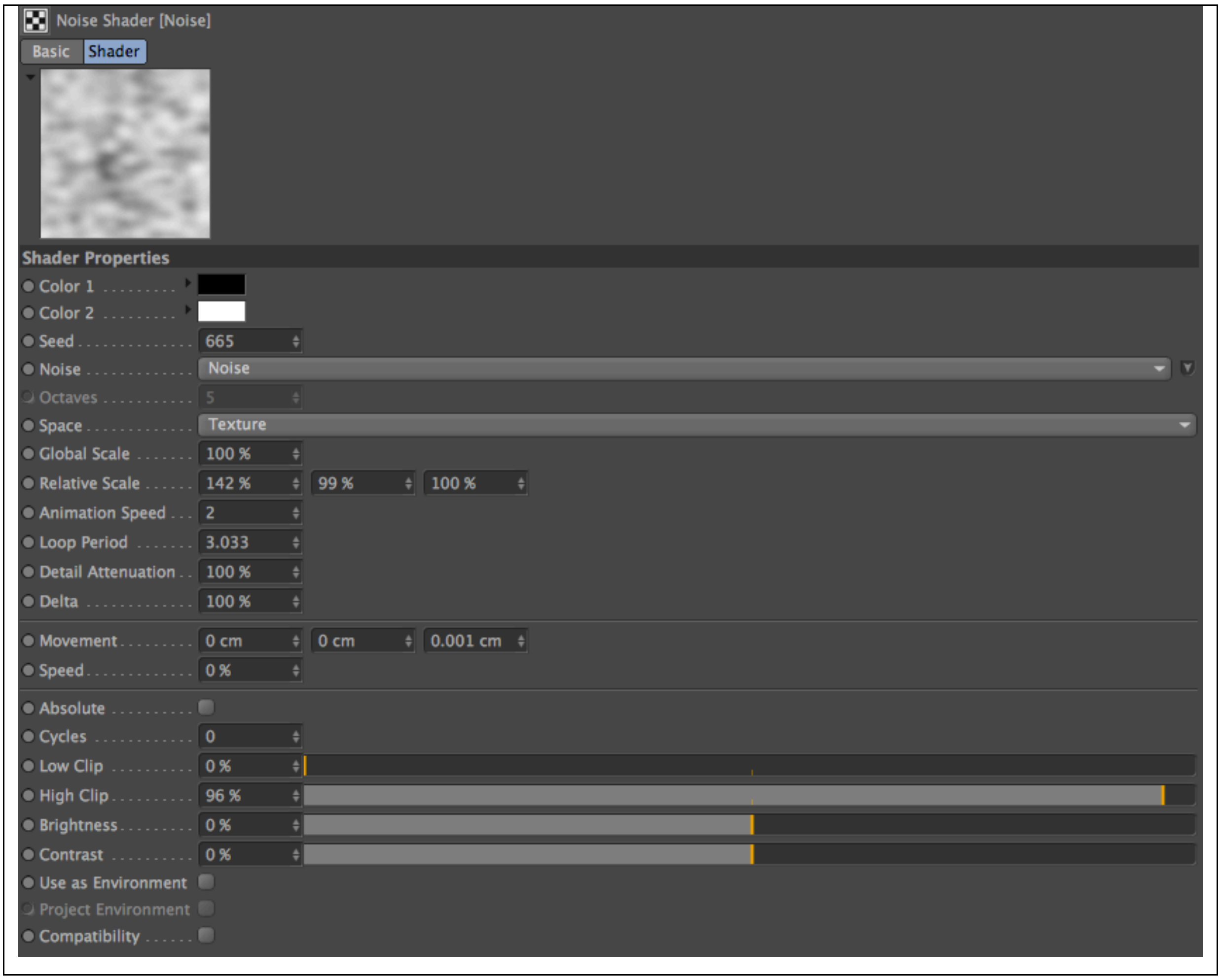


Figure 4.8 – The attributes set on the Noise Shader that was used to create the ocean chop animation on the WaveWatch

While creating the chop of the ocean was relatively simple, creating a cresting and breaking wave was more difficult. This was partly due to the nature of modelling moving water and therefore waves. Typically specialised software such as RealFlow (Realflow.com, 2015) is required to create simulated fluids. The software to create dynamic fluid models is often expensive and complex. Fluid dynamics calculations can also be processor intensive and for this reason there was a concern that real-time rendering of wave behaviour would not be possible. An alternative solution was to pre-render the wave scenes and where possible leverage pre-existing tools for generating waves in Cinema 4D.

A number of different methods were trialled in an effort to create a cresting wave before the final method was chosen. The early models utilised a plane with a cloth collider tag applied. Once animated a non-visible cylinder would ruffle the simulated cloth into a cresting wave shape. This method was ultimately abandoned due to its unrealistic nature and overall lack of aesthetic appeal. In place of this method a Cinema 4D plugin called Wave Deformer (Kollender, 2014) was utilised to create the realistic waves visible on the WaveWatch.

Wave Deformer is designed to allow the creation of realistic cresting waves in Cinema 4D. Written in C++ the object generated by the plugin is applied to a plane that is then deformed into the shape of a wave. The plugin is powerful in that a number of parameters can be edited to change the appearance of the wave including twist amount, width, falloff, texture, texture offset and bend (Kollender, 2014). A description of each of these parameters is visible in table 4.2.

Table 4.2 – The parameters of the Wave Deformer plugin (Nelson, 2013).

Parameter Name	Description
Twist Amount	Defines the overall size of the wave.
Width	The overall width of the wave.
Falloff	The distance from which the wave begins to dissipate along its horizontal axis.
Texture	A texture that can be used to influence the wave's twist amount
Texture Offset	This parameter can be used to animate the applied texture to create more realistic waves.
Bend	This parameter can be used to create curved waves.

Manipulating these parameters allowed the various WaveWatch scenes to be modelled and subsequently rendered. Finding the most appropriate settings for creating the required twenty levels of differentiation was largely a case of trial and error and this was considered in more detail during the data mapping stage. At this stage the focus was on creating an overall aesthetically pleasing composition.

4.3.6 Render 3D Scenes

Each of the thirty second scenes for the WaveWatch were rendered in Full HD (1920X1028) at thirty frames per second. Emerging as an issue throughout this process was the time to render each of the photorealistic scenes. Using a consumer grade personal computer it took two and a half months to compose and render each of the twenty scenes required for the WaveWatch.

A Dell XPS 8500 manufactured in 2012 was used to render each of the scenes. In terms of specifications, the system incudes an Intel Core i7 processor (3rd generation) clocked at 3.4GHz, an AMD Radeon HD 7770 (2GB GDDR5) and 8GB of main system memory. Using this system each thirty second scene took an average of 20 hours to fully render using the default render settings in Cinema4D.

This rendering process was lengthened by the high resolution of the scene, the high quality models, the high number of plane subdivisions required to animate the scene's ocean and the high quality horizon lighting. Although each of these elements increased the time needed to render each scene they each enhanced the overall aesthetics of the rendered output. Therefore, they were included despite their processor intensive nature.

Ideally such a graphics intensive scene could be rendered on a computing cluster in order to decrease the rendering time. Due to the iterative nature of the design process which required rendering twenty animated scenes for each iteration of the display, it took over ten weeks to generate and assess the various WaveWatch prototypes. This process extended the overall rending time, where the iterative nature of design refinement did represent an unexpected challenge in creating the WaveWatch display. Although subtle changes were made to try and improve the display's quality with each iteration, it was not always clear if the rendered outcomes would be aesthetically appropriate. This represents a potential risk when designing such displays as this iterative refinement and subjective-based quality assessment made it difficult to plan the exact project deliverable dates.

4.3.7 Evaluate Display Aesthetics

The initial prototyping focused on the trying to develop an aesthetically pleasing display, an important feature of the *Aesthetic Awareness Display* design pattern we were investigating.

Trying to assess aesthetics is by nature a very subjective task and to assist in this process the aesthetic direction of each prototype was informed by an experienced artist, who helped judge the overall aesthetic appeal of each successive WaveWatch prototype. Despite this feedback, there were pragmatic trade-offs required as we had restricted the modelling possibilities by deciding to use pre-existing modelling tools. This reuse saved considerable time but ideally the aesthetics may be improved if we allowed for more artistic freedom and had the resources to develop purpose built models and specific wave generation algorithms.

In this section we try to capture some of the key aesthetic issues that arose during the project and the evolution to the look and feel of the final prototype.

In the first prototype a scene was created where a realistic ocean wave existed solely on a black background (See Figure 4.5). This initial proof of concept prototype was successful in demonstrating ocean turbulence and waves. However, the abstracted wave was disconnected from the black background, especially between waves when it appeared as a simple plane of colour. The overall scene also departed from the idea of a dynamic and more natural seascape that we thought would be most appropriate for the potential users of the display.

Therefore the second prototype (See Figure 4.6) aimed to incorporate the qualities of the wave from prototype one into a more natural seascape scene. The second prototype incorporated a realistic beach and sky. Integrating each of the realistic scene elements along with the ocean wave created a much more complete looking scene that was more aligned to the notion of a seascape. Although the more natural scene aligned better to our aesthetic intentions, the overall composition of the scene lacked aesthetic emphasis and there was a disconnect between the highly realistic beach and the partly realistic ocean of the scene.

This disconnect between the highly realistic beach portion of the scene and the less realistic ocean, created a look that was akin to the Uncanny Valley in character design, which refers to the sense of unease that a viewer may feel when observing realistic character models. (Brenton, Gillies, Ballin & Chatting, 2005). This unease is often triggered by highly realistic representations of humans, where a mismatch between realism and believability may occur (Brenton, Gillies, Ballin & Chatting, 2005). A similar mismatch occurred in the second prototype of the WaveWatch due to to the highly detailed colours and textures of the beach and the plainer more abstract surface of the ocean. This uncanny inconsistency was further compounded by the photorealistic sky and scene lighting. To generate the waves, the ocean plane needed to be positioned as though it floated just above the beach surface, this produced the additional side effect that the horizon was also unrealistic. Due to these factors a third and final prototype of the scene was developed focusing on remedying these issues.

For prototype three, the focus was again on improving the aesthetic appeal by adjusting the scene's layout and composition and by reducing the scene's "uncanny" features. Two main elements of the scene were changed. Rather than an overhead perspective (as seen in prototype two), the view of the scene was changed to mirror the first person perspective of someone standing on the beach. This change created a more typical and realistic ocean scape with waves rolling in from the horizon and moving towards the beach. This perspective change resulted in a scene with a more natural look.

The second change to the aesthetic was to try and make the realistic beach scene more abstract in order to match the style of the less realistic ocean. This was achieved through changing the colour of each of the beach's elements to give them a semi-realistic look. For example, brighter greens were used to give the scene's foliage a cartoon-like aesthetic in order to match the semi-realistic ocean of the scene. In addition to these texture and colour changes, less realistic bright light was applied to the scene to provide consistent white light throughout and remove the stark shadows as seen in prototype two.

4.3.8 Data Mapping

The WaveWatch display utilises high definition pre-rendered 3D graphics in order to display a typical beach scene to the user. The ocean of the scene is used to visualise the number of active users on a webpage. As a whole a simple mapping is used where the intensity of the ocean scene mirrors the number of active webpage users.

After finalising the look and feel of the graphics for the display, the various levels of the twenty different scenes needed to be adjusted to ensure an appropriate mapping from the web activity data to the various levels of activity in the WaveWatch display. Once again there were subtle changes required to finalise the data mapping, each required more adjustments to the parameters in the wave generation model and rendering of the scenes. However, this phase marked a shift from aesthetic considerations to concerns with the functionality of the display. It was intended to create twenty distinct levels of ocean activity. This was an arbitrary number selected during the data characterisation phase. While it was not critical for the user to identify precise levels of activity (eg level 13) it is desirable that the scenes present a sensible scaling so that higher levels are identifiably greater than the medium and low levels of activity.

Of the twenty WaveWatch intensity levels, an intensity level of around 1 would indicate low levels of web traffic, an intensity level of ten would indicate a medium level of web traffic and an intensity level of twenty would indicate a very high level of web traffic.

Five main elements of the scene can change in order to visualise web traffic, namely the level of ocean chop, the presence of an ocean wave, size of an ocean wave, speed of an ocean wave and frequency of ocean waves. Each of these elements are explained in further detail below and summarised in Table 4.3.

The level of ocean chop is an element of the scene's ocean that is visible in all twenty intensity levels (see figure 4.9). Starting at level one the height of the ocean chop is low indicating a low number of active users on the webpage. The level of ocean chop changes in sync with the number of visitors to the webpage.

Progressing up through the levels of ocean intensity, the chopping motion of the scene's ocean becomes taller in height and more turbulent as more visitors become active on the webpage. The height and turbulence of the ocean's chop reaches its limit at intensity level Six, where other elements are introduced into the scene to indicate higher levels of web traffic. These additional elements are described below.

The first six levels of activity only use chop to represent activity. As web traffic increases an ocean wave is introduced into the scene. Through subsequent levels the height of the wave changes directly in relation to the levels of web traffic, changing from 1 cm in level 7 through to 18 cm in level 20. These numbers were found by some trial and error and relate to parameters in the wave modelling tool. Basically, waves grow larger as web traffic increases.

During times of medium levels of web traffic only one wave will be visible every thirty seconds, while three waves will be visible over thirty seconds during the high levels of web traffic. A detailed description of the data mapping for each of the WaveWatch’s intensity levels is visible in Table 4.3.

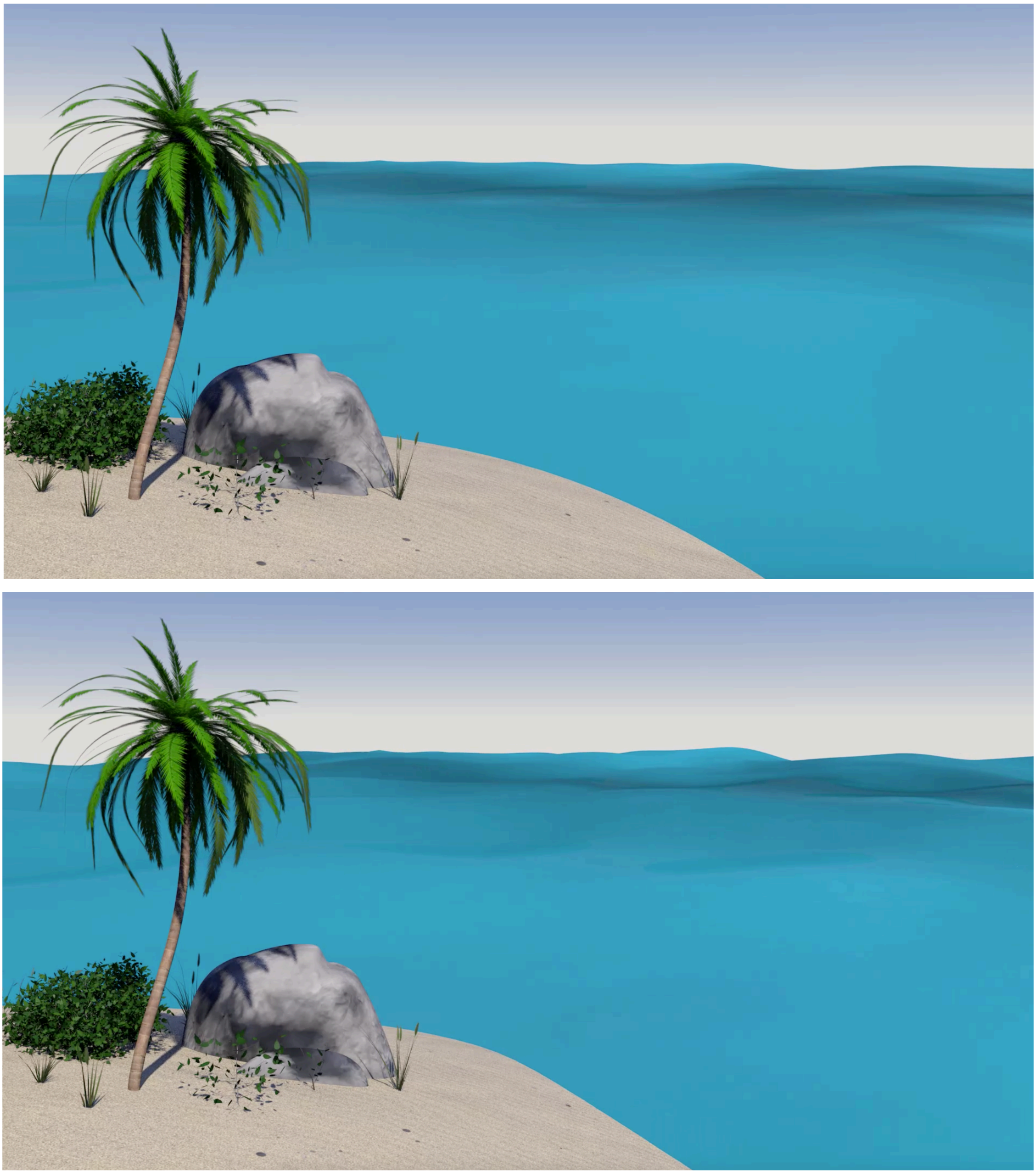


Figure 4.9 The WaveWatch displaying varying levels of chop intensity. Lowest (level 1) and highest chop level (level 6) are shown with a visible increase in the water's height

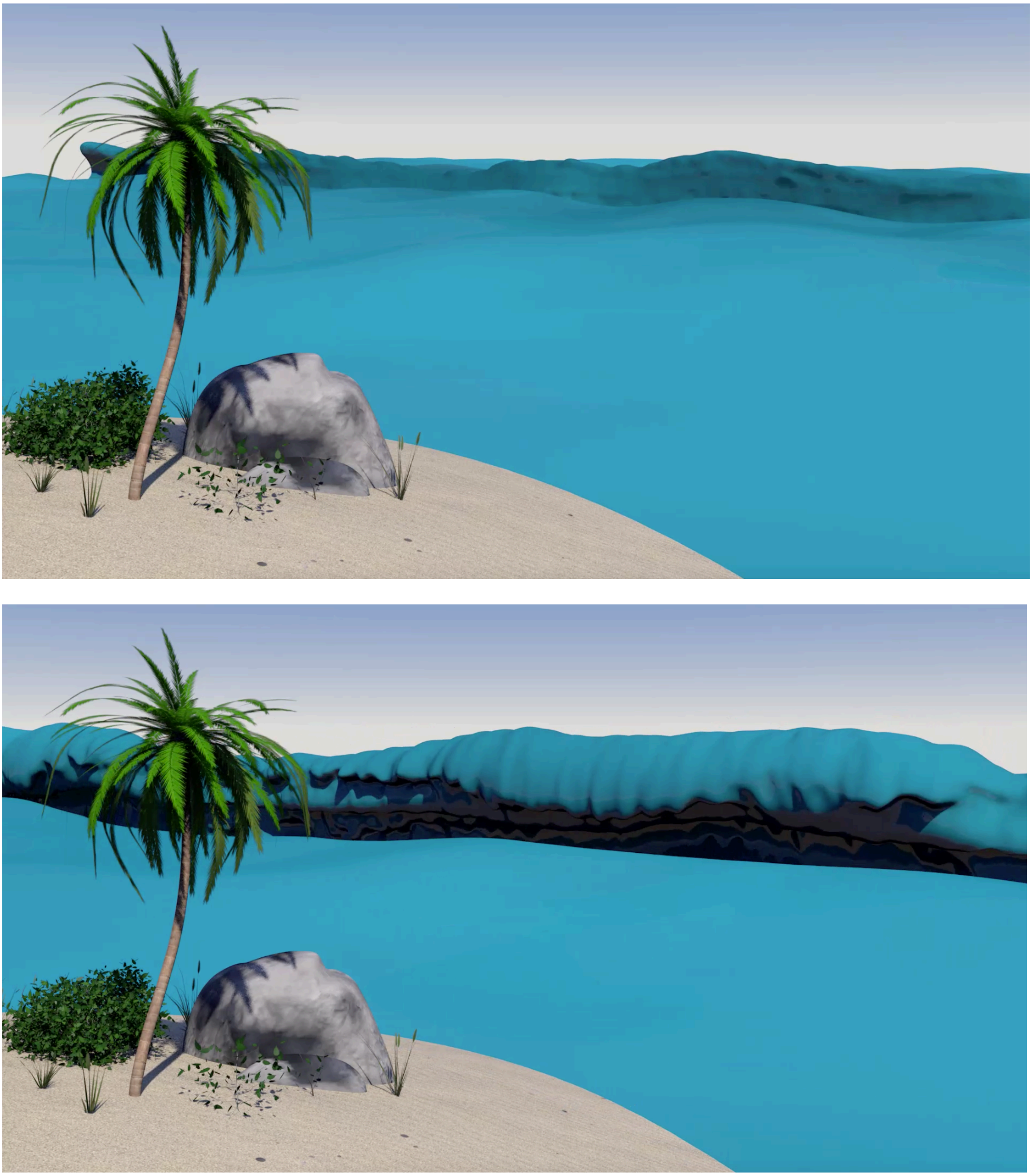


Figure 4.10 – The WaveWatch displaying an ocean wave. A small (level 9) and large (Level 14) wave are shown.

Table 4.3: The WaveWatch intensity Levels

	Level	Chop Height	Wave Height	Wave Frequency Per 30 secs
Low	1	0.7 cm	0cm	0
	2	0.95 cm	0cm	0
	3	1.1cm	0cm	0
	4	1.20cm	0cm	0
	5	1.35cm	0cm	0
	6	1.60cm	0cm	0
Medium	7	1.60cm	1cm	1
	8	1.60cm	2cm	1
	9	1.60cm	3cm	1
	10	1.60cm	4cm	1
	11	1.60cm	5cm	1
	12	1.60cm	6cm	1
High	13	1.60cm	7cm	3
	14	1.60cm	8cm	3
	15	1.60cm	9cm	3
	16	1.60cm	10cm	3
	17	1.60cm	11cm	3
	18	1.60cm	12cm	3
	19	1.60cm	15cm	3
	20	1.60cm	18cm	3

An important issue identified at this stage was the difficulty of creating a seamless link between the various intensity levels. This would make changes in animation levels obvious due to the lack of continuity between each of the renders. For example, when transitioning between level 9 and level 10, differing chop heights and shapes on the last frame of level 9 and the first frame of level 10 would be noticeably disjoint.

In order to create a loop-able ocean, important modifications were made to the rendered scenes. The ocean chop without a wave present was standardised at the end and the beginning of each scene. As a second measure to ensure that both the first and last frame of each scene were consistent, a loop period on the noise displacer that was used to create the ocean chop effect was added (a loop period of 3.033 was used). Implementing these subtle changes guaranteed that the first and last frame of each scene were consistent, allowing for seamless transitions between the twenty animated activity levels. This was important where the intention of the Ambient Display was to avoid distracting users with jarring changes in the display's animation.

4.3.9 Implementation and Testing of Prototype

Once each of the twenty animated scenes for the WaveWatch were rendered and the data mapping was finalised, the functionality of the software required to run the display became the key focus. The key requirement for the software was that it track web activity at regular intervals (60 seconds) and display the appropriate wave animation based on the level of activity occurring on the webpage. The number of users on the webpage was directly matched to one of the twenty levels of ocean activity by using the levels previously characterised in the requirements gathering phase.

This phase involved finalising the architecture and writing as well as testing the elements of the software needed to run the display. This phase was partially iterative and featured traditional implementation and testing steps to produce the software that controlled the prototype.

The WaveWatch was created through a combination of currently existing technologies. Table 4.4 shows the three main components of the WaveWatch display and the technology that was used to build each of these. These technologies include Cinema 4D (Maxon.net, 2015), Windows Presentation Foundation C# (Msdn.microsoft.com, 2015), and the Google Analytics Real Time Reporting API (Google Developers, 2015) (See figure 4.11). Combining each of these technologies into an Ambient Information System required around 200 man hours.

Table 4.4 Each of the components of the WaveWatch and the technology used to build it

WaveWatch Component	Technology
Native Windows Application	Windows Presentation Foundation C# (Msdn.microsoft.com, 2015)
Wave Renderings	Cinema 4D (Maxon.net, 2015)
Live Web Data Scrapper	Google Analytics Real Time Reporting API (Google Developers, 2015)

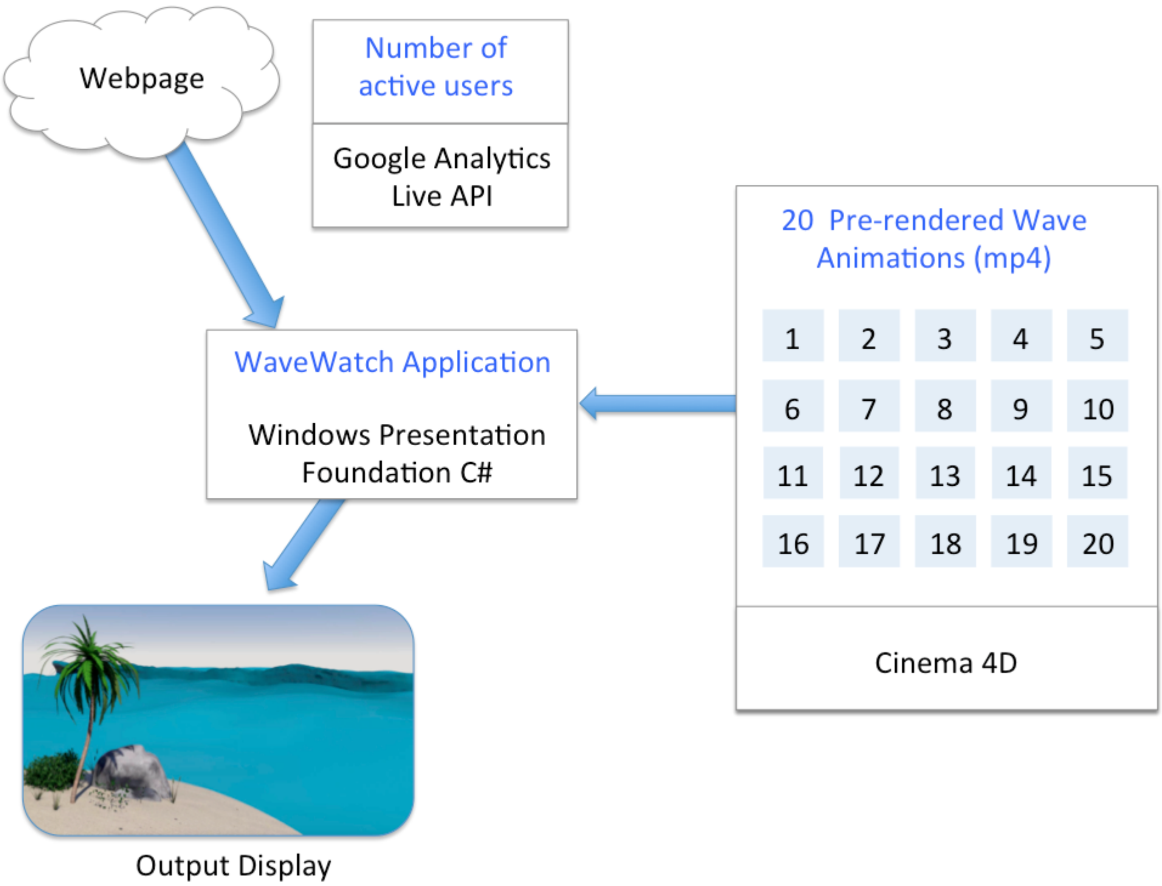


Figure 4.11: The hardware and software used to create the WaveWatch

The Live Web Data Scrapper is a critical part of the WaveWatch responsible for gathering the real-time data that is visualised by the display. The Google Analytics Real Time Reporting API (Google Developers, 2015) was used to create the Data Scrapper for the WaveWatch. The Real Time Reporting API was found to be suitable due to its ability to gather a number of traffic related website metrics in real time.

Each minute the Data Scrapper of the WaveWatch determines the number of active users on a webpage. It is this number that is then visualised by the WaveWatch. The Data Scrapper of the WaveWatch was implemented in C# as part of the native windows application that powers the display.

The WaveWatch itself is a Native Windows Application. Once launched a full screen window appears presenting the wave visualisations. Created in Microsoft Visual Studio the WaveWatch application utilises the Windows Presentation Foundation (WFP) in C# (Msdn.microsoft.com, 2015).

The application itself utilises a multithreaded model. Two application threads are used, one that collects data from the Google Analytics Real Time Reporting API every sixty seconds and the other controlling the wave visualisations that are presented to the user (See Figure 4.12). Every 60 seconds the WaveWatch updates the on screen visualisation to reflect the number of users on a webpage at that time. The current on screen visualisation is looped if an update is not required or only 30 seconds have passed. Looping the pre-rendered videos in Windows Presentation Foundation C# was challenging due to the limitations of the inbuilt video player that WFP offers.

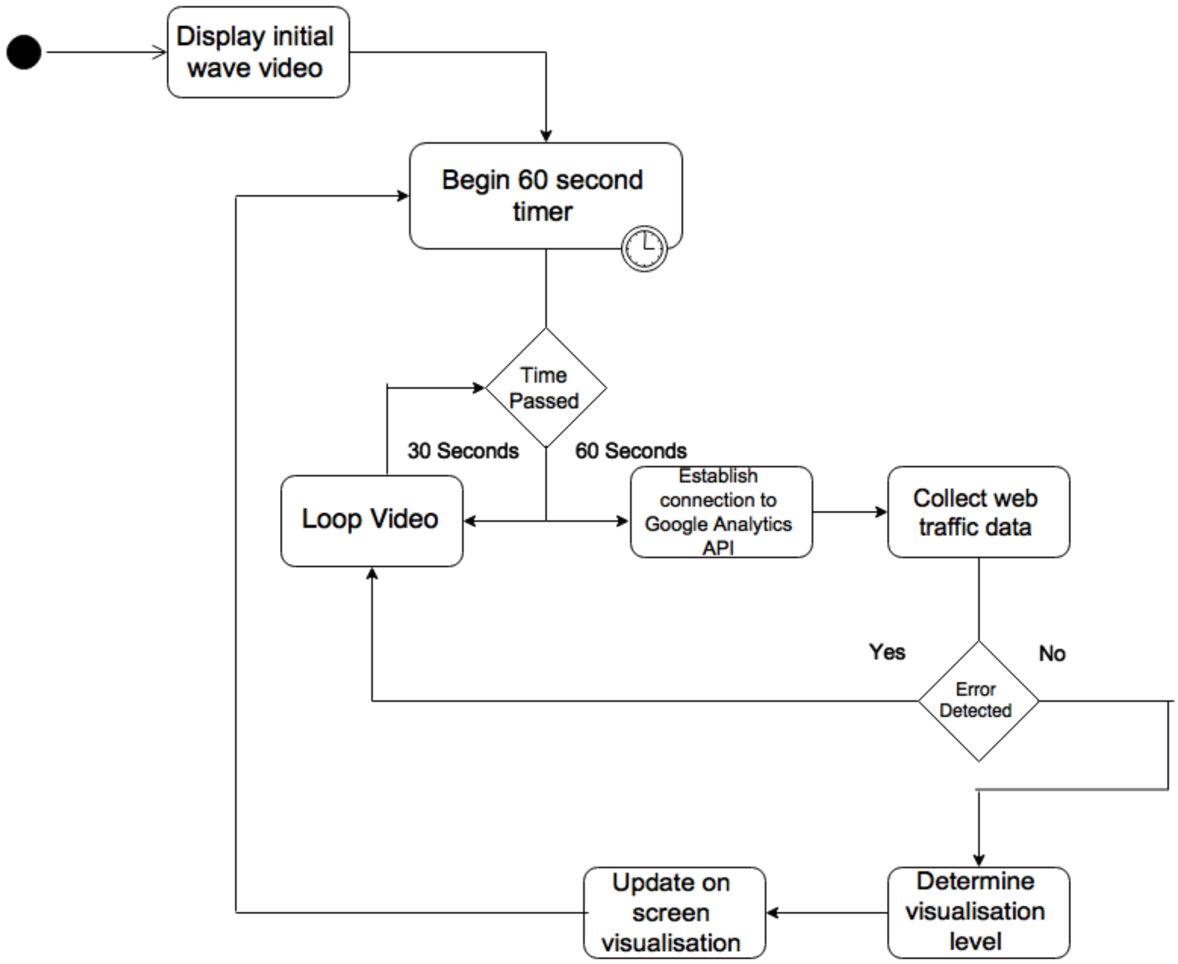


Figure 4.12 A UML process diagram showing how the WaveWatch functions.

As previously noted it was important to create smooth transitions between the animated sequences to ensure that they looped seamlessly. Any obvious change in the visual display could quickly create a distracting and non-calming experience for the users. While we had made subtle changes to the beginning and end of each render, we also encountered a problem when trying to load and play these scenes in the WaveWatch, WFP C# application.

A common method to add a video to a WFP application is to use the WFP MediaElement (Msdn.microsoft.com, 2015), this approach was used to create the WaveWatch prototype. Although the MediaElement simplifies the process of adding and playing videos in a WFP application, the MediaElement is somewhat limited and inefficient at looping videos.

Problems arose when trying to switch from one WaveWatch level to another, for example when there is an increase or decrease in the number of users on a webpage. The first method created to do this involved switching the source of the media element once a larger or smaller wave scene was needed. In testing this method, it was found to be inefficient as the MediaElement would firstly remove its currently playing video and then load the next video file into memory and then render it onto the screen. This resulted in a blank screen or a black flash being visible for approximately half a second between the two scenes. A number of techniques were explored to try and eliminate this issue.

As a first step the use of animated gifs was explored in placed of mp4 video files due the ability of GIF files to be easily and seamlessly looped. However, this method needed to be abandoned due to the lossy compression that is used by GIFs, making the files large and slow to load into memory. Several tests were tried with GIFs but a consistently smooth frame rate was not achievable. After the use of GIF files was found to be inappropriate it was decided that the initial mp4 file format would be utilised due to its compromise between a relatively small file size and high quality. Although mp4 files were found to be an efficient file format for the WaveWatch, black flashes were still occurring when the program changed the on screen intensity level.

To switch seamlessly between animations required the implementation of two MediaElements into a single WFP application. These two MediaElements were placed on top of each other on the application's interface. The first MediaElement that appeared on top of the second MediaElement would play one video. When the second video needed to be played it would be loaded onto the second player hidden behind the first. This second player would then be brought in front of the currently playing video that is sitting on top of it, to give the effect that the video had switched. Ultimately the WaveWatch relies on this method of switching between two stacked MediaElements in order to create smooth playback whenever a new wave level is loaded. This method was successful in eliminating the black transition frame.

4.3.10 Deployment

After the software had been developed, a two week trial of the WaveWatch was undertaken to determine the overall quality of the display's software when ran for an extended period of time. During this two week period a few issues were found that were remedied before the implementation of the WaveWatch was performed.

There were two types of issues that occurred during this testing period, namely bugs in the software and issues related to other programs running on the computer. One software bug was found during the initial testing period that would cause the WaveWatch to freeze. This issue was easily recognised as a simple programming error and was remedied. The second issue found during this testing period was related to the background programs running on the computer that would occasionally interrupt or minimise the WaveWatch if they required updating or direct input from the user. This issue was eliminated by removing or disabling all unnecessary software that was running on the computer during the implementation of the WaveWatch.

Figure 4.13 - The WaveWatch being tested on a computer monitor.

After testing the WaveWatch for a period of two weeks the software powering the display was found to be stable with no crashes recorded after the freezing bug was eliminated. The prototype was deemed to be ready for the in-situ evaluation, which is discussed in the next chapter

4.4 Conclusion

Through an iterative design process a 3D High Definition Ambient Information System, the WaveWatch was created through a combination of existing technologies. The WaveWatch in itself is a native windows application that displays a different pre-rendered video of an ocean scene dependent on the number of active visitors on a webpage.

Although there were many challenges in creating the WaveWatch, compromises were made and novel technological solutions were implemented in order to create a new Ambient Display. These challenges were based around the time required to render each of the scenes, the difficulty in creating loop-able video files and the currently available technologies in WPF C# which made seamless video swapping difficult.

The WaveWatch was designed to be implemented into the M&PR office at The University of Newcastle, Australia. The details around this implementation and the evaluation of the WaveWatch are discussed next in chapter five.

Chapter 5

Case Study and evaluation

Chapter five examines and analyses the results of the WaveWatch case study. The WaveWatch case study was undertaken to attain a better understanding of the performance and utility of a novel Ambient Display in a real life environment.

Chapter five discusses the Self-Completion Questionnaire that was performed to measure the perceived usefulness of the WaveWatch. Also discussed is the data that was collected from the Self-Completion Questionnaire and the findings that were attained through this process.

5.1 – Research Methods

As discussed in chapter three an Instrumental Case study method was chosen in order to evaluate both the feasibility and utility of the WaveWatch in an office environment. The specifics around the case study implementation are discussed below.

After a period of testing, the WaveWatch was implemented into the Marketing and Public Relations (M&PR) office at The University of Newcastle, Australia. The WaveWatch was made to visualise the number of active users on a popular webpage on The University of Newcastle's website, which is managed by the M&PR team. WaveWatch was made to compliment the current web traffic reporting activates undertaken by the M&PR team through raising the awareness of web traffic volumes and patterns through the provision of web traffic data in the periphery.

The WaveWatch was implemented into the M&PR office onto a large LCD screen television (HD 1920X1080). The television is immediately visible from a number of workstations in the office as well as being visible upon entering and existing the area.

Figure 5.1: The WaveWatch display installed into the M&PR office at The University of Newcastle, Australia.

To ensure an understanding of the WaveWatch was held by the M&PR team prior to the display's implementation, a number of communication tools were used to ensure that the display's metaphor and intent were understood by the team. This was done to ensure that staff taking part in the Self Completion Questionnaire had an adequate understanding of the metaphor utilised by the WaveWatch and the data that it was displaying.

Firstly, the concepts of Ambient Information System and the WaveWatch were introduced at the M&PR monthly meeting, this was followed up by an email to the M&PR team notifying them of WaveWatch's implementation date. Attached to the email was an Information Participant Statement that reiterated the concepts of the WaveWatch and explained the Self Completion Questionnaire. The Participant Information statement that was sent to the M&PR team is visible in appendix A.

After the intent of the WaveWatch was communicated, the display was implemented into the M&PR office for a period of two weeks. During this two week period the WaveWatch ran for 24 hours a day 7 days a week in order to increase the ubiquitous nature of the display. The WaveWatch was technically successful during this period in that it ran continuously without encountering any errors, therefore increasing its ubiquitous nature through its constant runtime and the lack of human intervention needed to ensure that the software ran continuously.

After the two week implementation of WaveWatch was complete a follow up email was sent to the M&PR team giving them the chance to complete the Self-Complete Questionnaire. The Self-Complete Questionnaire was comprised of two previously defined technology surveys, the Heuristic evaluation of Ambient Displays (Mankoff et al., 2003) and the Perceived Usefulness and Ease of Use survey (Davis, 1989). The results of the Self-Complete Questionnaire are discussed in section 5.3 and 5.4.

5.2 - Survey Results

A total of 15 M&PR staff members completed the Self-Completion Questionnaire conveying their experience with the WaveWatch after its two week implementation into the M&PR office. The data that was collected through the Self-Completion questionnaire is visible in tables 5.1 and 5.2.

The Self-Completion Questionnaire (visible in appendix A) consisted of a number of Likert Scale questions as well as a number of open ended questions. The responses that were collected through each question of the Self-Completion Questionnaire are presented below (full results visible in appendix B).

5.3 Heuristic Survey Results

As discussed in chapter three, a set of Heuristics created specifically for evaluating Ambient Displays were adapted into a set of survey questions to allow the simple collection of Heuristic data through a Self-Completion Survey. The data collected through the Heuristic survey is visible in table 5.1.

Generally speaking, the data collected through the Heuristic survey revealed that staff of the M&PR office found the WaveWatch to be useful and easy to use. This finding and as well as a number of others are discussed below in relation to the Heuristic survey data that was collected through the Self-Completion Questionnaire and the related open ended survey questions.

Table 5.1 – Data collected from the Heuristic Survey

Question	Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely Agree
The information displayed on the WaveWatch display was relevant and useful.	0	0	2	6	7
The WaveWatch display was obtrusive or interrupting to your everyday work.	13	1	0	1	0
The display attracted the attention of others.	0	0	2	7	6
There was too much information displayed on the WaveWatch display.	11	3	1	0	0
I was able to easily understand the information conveyed through the WaveWatch display.	0	2	1	5	7
I was able to understand the overall content of the display when glancing at it.	0	0	1	6	8
The WaveWatch display is aesthetically pleasing.	0	0	1	6	8

5.3.1 - Findings Heuristic Survey

A number of findings were ascertained through analysing the responses to the Heuristic survey. These findings are discussed below in relation to each survey question.

Participants found the data presented on the WaveWatch both relevant and useful

86.6% of respondents answered positively when asked to reflect on the utility of the data that was presented on the WaveWatch. This result was also reiterated through a related open ended question where respondents answered favourably when asked to reflect on the relevance of the data presented on the display.

In analysing responses to the related open ended question "*Do you have any other comments in relation to the relevance of the information presented on WaveWatch?*" it was determined that participants found the data presented to be useful, with favourable responses such as "very interesting", "I often found myself checking and wondering about trends/time of day/what was contributing to wave" and "It was very unobtrusive" being recorded.

In addition to these broadly positive comments another trend emerged around the translation of data into waves. It was suggested by two respondents that without previous knowledge one would not be aware of what the WaveWatch was visualising*, "It would've been good to recieve a scale at the start to know what the small waves vs. tsunamis are.", "If you weren't directly informed that the wave represented the homepage views you wouldn't know what is was for*". Although both respondents raised the fact that the WaveWatch does require previous knowledge to be understood, this may be a positive in a semi-public office space where the data being presented on the WaveWatch may be private or non-relevant to uninformed users. The idea of supplying a scale of the display's visualisations to relevant staff members may increase the ease of use of the WaveWatch.

The display was found to be unobtrusive and un-interrupting.

It was found through the second Heuristic survey question that 93.3% of respondents perceived WaveWatch to be both unobtrusive and un-interrupting to their everyday work. This was backed up through the related open-ended question where the calming aspects of the WaveWatch were discussed by a number of respondents, some typical responses included:

- "*The design wasn't harsh in colour or movement*",
- "*Very calming image, colours weren't too distracting*"
- "*It was subtle, no noise, no jolting movement*"
- "*It was magnificent to see information displayed in this manner! I enjoyed the theme, as I found it quite relaxing, enjoyable and informative to consume*"
- "*the information represented isn't like an 'alert' requiring immediate response*"
- "*The blue colour and wave motion are effective in that way too - there's no sudden or bright contrasts that would demand attention*".

In analysing these responses it does become evident that the aspects of Calm Computing that were considered when creating the WaveWatch do seem to have had a positive effect on the display, where the WaveWatch was perceived to be both calming and non-alarming by respondents.

The display was able to attract the attention of others.

86.6% of respondents agreed that the WaveWatch was able to attract the attention of others. This result is particularly noteworthy when keeping in mind that the display was perceived by the majority of participants to be both unobtrusive and un-interrupting. In reviewing the responses to the related open ended question, it was found that social factors may have been a reason as to why the WaveWatch was able to attract the attention of others.

Some typical responses to the question "*How did the WaveWatch display attract your attention?*" include:

- "*It generated conversation amongst staff who worked within the area*"
- "*Other departments who visited commented positively on the design and when they were told what it was representing they often asked if they could have a similar design installed in their offices. Very impressive.*"
- "*The large waves attracted attention and generated much discussion about what time of day it was and the causes of high traffic volumes*", "*It made me and stakeholders who entered the unit very interested in the traffic to the site and was a conversation starter!*".

It is a possibility that the WaveWatch was able to draw the attention of others not through interrupting or alarming visualisation, but through social means. This social aspect of the display does reveal the power of the WaveWatch to create awareness around a single metric but to also generate interest around web traffic through the use of a novel technological device that has the potential ability to generate social interest.

The WaveWatch did not display too much information.

It was indicated by 93.3% of respondents that the WaveWatch did not display too much information when asked to reflect on the statement "*There was too much information displayed on the WaveWatch display*".

This was reiterated in the related open ended question where a number of respondents indicated that they would like the display to convey more than a single data source. Some typical responses included:

- "*Other elements - crabs, coconuts, surfer, breeze on the tree, etc - could be brought in to represent other web traffic elements*"

- *"It was interesting enough to watch with the single data source. But would be happy for other elements to represent other data sets."*

- *"Actually think we could display more*"

- *"Simple enough to be accessible, complex enough to be interesting*."

Although the WaveWatch was designed to explore an Ambient Information System that displays a single metric, respondents revealed that they did not experience any type of sensory overload in relation to the display and would therefore like other elements of the scene visualised to display an additional data source. Further research will be required to determine the optimum number of data sources to find an acceptable mix between the number of information sources presented and the levels of information overload experienced by users of such a display.

Participants were able to easily understand the data displayed on the WaveWatch

It was found that the use of an ocean wave metaphor to convey real time data was able to be easily interpreted, where 80% of respondents agreed that they were easily able to understand the information conveyed through the WaveWatch. This was reiterated through the related open ended question, where some typical responses included:

- *"It was easy and also generated excitement when the traffic was huge*"

- *"The metaphor of the waves bigger being more visits was a really good visual cue*"

- "*Small waves = less traffic. Large waves = more traffic. Simple concept to grasp"*

- "*Simple metaphor, easy to understand*"

- "*Wave was a simple metaphor to interpret*"

In analysing the responses, it is evident that the wave metaphor was perceived by 80% of respondents as an easily understandable data visualisation. In addition to these positive comments it was once again reiterated by two respondents that the creation of a scale to inform users of the WaveWatch levels could make the display easier to understand.

The WaveWatch's metaphor was *glancable*

It was revealed through the Heuristic survey that the WaveWatch's metaphor could be easily understood at a glance, with 93% of respondents agreeing that they were able to understand the overall content of the display when glancing at it. This characteristic of the display was reiterated through the responses to the open ended question "*Did you notice any interesting patterns in the display that you would like to share?*". A number of respondents revealed that they were able to gain an awareness of web traffic patterns through the WaveWatch. Some typical responses to this question included:

- *"There were always peaks at about 3pm in the afternoon"*
- *"Yes, I saw patterns of frequency and volume"*
- *"The larger waves in the morning and also around lunchtime"*
- *"Approx. midday and around 3pm daily the size of waves clearly demonstrated a large amount of traffic to the site"*

The WaveWatch was perceived to be aesthetically pleasing

It was indicated by 93% of respondents that they found the WaveWatch to be aesthetically pleasing. This is a positive result for the display as aesthetics are an important aspect of the *Aesthetic Awareness Display* design type and Ambient Information Systems in general. The aesthetics of the WaveWatch were reflected on by the staff of the M&PR office with several participants commenting on the aesthetic and calming nature of the display, some recorded comments include:

- *"Colours, subtle movement and theme of the display all contributed to the pleasing aethestics of the display. Blue is really calming"*
- *"Very calming and enjoyable, a welcomed change to my busy and sometimes stressful role"*
- *"Reminded me of a holiday/somewhere relaxing"*

- "*Nice calming aesthetic"*

5.3.2– Summary Heuristic Survey

In summary, when analysing the results of the Heuristic survey it becomes evident that the majority of respondents found the WaveWatch to be useful, easy to use, relevant, non-interrupting and aesthetically pleasing.

In addition to these findings a number of respondents reflected on their desire for the WaveWatch to not only utalise visuals to represent web traffic but sound also. This is an aspect of Ambient Media that was not explored through the WaveWatch but does require further research, particularly in relation to an ocean metaphor due to respondents commenting on the calming aspects of the display's ocean. This aspect of WaveWatch may have the capacity to be translated into an audio or audio/visual based Ambient Display.

Largely the results of the heuristic survey were positive with few refinements to the interface of the WaveWatch being suggested. One such suggestion did centre on the translation of the real time data into waves:

- "I remember noticing a really big wave once in a while on a generally calm sea - perhaps a spike in data. It might have been better to have a 'feel' across a broader amount of time"

- "the sea was a representation of website traffic, and this seemed confirmed by the sea being visibly calmer at some times and there being a freak large wave once in a while, in general it was mostly about the same level of calm. Rather than calm with occasional spikes it should be more generally rougher and more generally smoother over broader periods of time"

Both of these comments do indicate that a higher level of temporal change or a higher number of WaveWatch intensity levels could increase the ability of the WaveWatch to display finer changes in web traffic levels as well as improve the ability of the display to better convey a range of similar levels over a period of time.

Both of these suggestions could possibly be more easily be incorporated into the WaveWatch if real time rendering was utilised rather than pre-rendered video files. The dynamic properties of the wave could be modified in real time over a larger and finer scale if real time rendering was implemented, but further research is required around the use of real time wave rending on an Ambient Display.

5.4– Perceived Usefulness and Ease of Use

The second half of the Self-Completion questionnaire was comprised of a Perceived Usefulness and Ease of Use Survey. This survey aimed to determine the utility of the WaveWatch in relation to the everyday work undertaken by the M&PR team.

The results of the Perceived Usefulness and Ease of Use Survey are visible below in table 5.2. The findings, which were ascertained through analysing each of the responses received, are discussed.

Table 5.2 - Results Perceived Usefulness and Ease of Use Survey

Question	Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely Agree
Using such a display in my job would enable me to accomplish tasks more quickly.	1	1	8	5	0
Using such a display could improve my job performance.	1	0	3	11	0
Using such a display in my job could increase my productivity.	1	0	5	9	0
Using such a display could enhance my effectiveness on the job.	1	0	7	7	0
Using such a display could make it easier to do my job.	0	1	5	8	1
I would find this type of display useful in my job.	0	0	2	9	4
I found the WaveWatch display to be easy to use.	0	0	1	6	8

In reviewing the results of the Perceived Usefulness and Ease of Use survey it does become apparent that respondents were indecisive when asked to reflect on the utility of the WaveWatch in relation to their job tasks, work performance, productivity and overall job effectiveness. This is reflected in the survey results where a proportion of respondents indicated that they neither agreed nor disagreed with a number of questions. This result becomes further evident when observing the results as percentages as shown in table 5.3.

Table 5.3 - Responses to the Perceived Usefulness and Ease of Use survey as percentages

Question Name	Total responses	Responses disagreeing	Responses neither agreeing or disagreeing	Responses Agreeing
Using such a display in my job would enable me to accomplish tasks more quickly.	15	13%	53%	33%
Using such a display could improve my job performance.	15	6%	20%	73%
Using such a display in my job could increase my productivity.	15	6%	33%	60%
Using such a display could enhance my effectiveness on the job	15	6%	46%	46%
I would find this type of display useful in my job	15	0%	13%	86%
I found the WaveWatch display to be easy to use.	15	0%	6%	93%

In reviewing each of the responses that were received through the Perceived Usefulness and Ease of Use survey a number of broad findings were ascertained. Each of these findings are discussed.

Participants were unsure if the WaveWatch could facilitate faster task completion.

In reviewing the responses to the first question of the Perceived Usefulness and Ease of Use survey it does become apparent that the majority of respondents were unsure if having the WaveWatch installed could allow them to complete their job related tasks more quickly

A small proportion of respondents did indicate that the WaveWatch could allow them to complete tasks quicker (33%) and a smaller proportion again indicated that the WaveWatch would not make task completion quicker (13%). Although 33% of respondents did reiterate that the WaveWatch could make task completion quicker, the majority of respondents (53%) were unsure if the WaveWatch could have a positive effect on their task completion time, indicating that improved task completion time was not a commonly perceived effect of the WaveWatch during its implementation period.

Participants found that the WaveWatch could increase their job performance.

In answering the question "Using such a display could improve my job performance." it was found that the majority of respondents (73%) answered positively, indicating that the WaveWatch could have the ability to improve overall job performance. This finding is particularly interesting when contrasted with the fact that respondents were unsure if the WaveWatch could allow them to complete tasks more quickly. This result would indicate that the WaveWatch could have a positive effect on job performance but not specially related to task completion time. The provision of an extra layer of useful and relevant data in the periphery related to the work of the M&PR team could have attributed to this positive result.

Participants indicated that the WaveWatch was able to increase their productivity

When answering the question "Using such a display in my job could increase my productivity." it was found that the majority of respondents (60%) agreed that the WaveWatch could increase their productivity.

Although the majority of respondents did perceive the WaveWatch as having the ability to increase their productivity, a smaller proportion (33%) were unsure if the display did have the capacity to increase on the job productivity.

Despite these differences, it is evident that during the two week case study 60% of participants did find that the WaveWatch could have a positive effect on their on their productivity.

Participants were either unsure or positive in relation to the WaveWatch's effect on job effectiveness

In analysing the results to the survey question "Using such a display could enhance my effectiveness on the job" it does become evident that two distinct groups of respondents emerge from the results set. The first of these were unsure (46%) if the WaveWatch was able to increase their on the job effectiveness and the other group agreed (46%) that the WaveWatch was able to increase their on the job effectiveness.

Although responses were mixed, it is evident that the WaveWatch was perceived by 46% of users as having the ability to possibly increase on the job effectiveness.

Participants found the WaveWatch to be useful in relation to their job

It was found that the majority of participants (86%) agreed that the WaveWatch was useful in relation to their job. This is a positive result for the display where despite mixed results in relation to the display's effect on job effectiveness and task completion time, 86% of participants still perceived the WaveWatch to hold a level of positive utility in relation to their job overall.

Participants found the WaveWatch easy to use

In confirming the results of the Heuristic survey, 93% of participants answered positively when asked to reflect on the statement "I found the WaveWatch display to be easy to use".

5.4.1 – Summary Perceived Usefulness and Ease of Use Survey

Through analysing the results of the Perceived Usefulness and Ease of Use Survey it does become evident that although a high proportion of respondents perceived the WaveWatch to have the ability to improve job performance as well as be useful in relation to their job, it was also reiterated that the WaveWatch was not perceived to increase on the job effectiveness or reduce the time to complete on the job tasks.

5.5 - Conclusion

Overall the contrasting results from the Perceived Usefulness and Ease of Use survey do reveal that the WaveWatch was perceived to be useful in terms of its overall utility, although this utility may have not translated into improved on the job effectiveness or improved task completion time. It would seem that the WaveWatch could be characterised as being a tool that is nice to have rather than a necessity for increasing job performance in an office environment. This was indicated where it was found that the WaveWatch was perceived to have the ability to increase overall productivity, but respondents were unsure if the utility of the WaveWatch translated into improved on the job effectiveness or improved task completion time.

Although the display's greatest attribute may not be related to creating reduced task completion time or on the job effectiveness, it is evident from the survey results that the WaveWatch was able to successfully use a wave metaphor for information transmission, be perceived as being useful in an office environment and be perceived to have a positive on some aspects of job performance. In addition to these findings respondents perceived the WaveWatch to be useful, easy to use, relevant, non-interrupting and aesthetically pleasing. Overall these results would indicate that respondents found positive utility in the provision of relevant peripheral data through an ocean wave metaphor, revealing the overall usefulness of an ocean wave for real time data visualization on an Ambient Display.

In addition to these results around the utility of the WaveWatch, it was also found through the case study that a combination of a Heuristic survey and a Perceived Usefulness and Ease of Use survey were a successful combination for gaining insights into the usefulness of an Ambient Information System during an in-situ implementation. The Heuristic survey provided insights into the perceived utility of the display's interface and the Perceived Usefulness and Ease of Use survey proved useful data in determining if participants found the display useful in relation to their job.

Chapter six expands on the findings discussed above through a synthesis of the findings gained throughout this thesis and a discussion on possible avenues of future work.

Chapter 6

Conclusions and Future Work

6.1 Conclusions

This thesis aimed to expand the current knowledge in the domain of Ambient Information Systems though the design, implementation and evaluation of a novel Ambient Information System, the WaveWatch. The thesis also proposed a new design type for the taxonomy of Ambient Information Systems, *The Aesthetic Awareness Display*. The Aesthetic Awareness display describes a subset of Ambient Information Systems that have low information capacity, medium levels of user notification, typically use metaphors for information visualization and have a high focus on aesthetics. Each of these elements of the *Aesthetic Awareness Display* were incorporated into the WaveWatch in order to explore the utility of the newly defined design type.

The research as a whole aimed to determine the feasibility of creating an Ambient Information System that visualised information through an ocean wave metaphor, the use of three dimensional graphics on an Ambient Information System and to determine the efficiency of the WaveWatch in a real life office environment. An instrumental case study was used to address each dimension of the research question.

Approximately 200 man hours were required to design, create, test and implement the WaveWatch, through the novel use of existing technologies. The technologies that were used to create the WaveWatch include Cinema 4D (Maxon.net, 2015), Windows Presentation Foundation C# (Msdn.microsoft.com, 2015) and the Google Analytics Real Time Reporting API (Google Developers, 2015).

Through this process it was found that it is possible to create an Ambient Information System that utilizes an ocean wave metaphor for information transmission. It was also found to be technically feasible to use three dimensional graphics to display a real time visualisation on an Ambient Information System.

Through the creation process of the WaveWatch challenges were encountered, namely in relation to the time to render the required scenes for the display, the difficulty in creating truly loop-able ocean waves and the limitations of current technologies in WPF C#, which made creating seamless video swapping difficult. These challenges were ultimately overcome through the novel combination of existing technologies into a new Ambient Information System. In addition to accessing technical feasibility, this thesis aimed to determine the utility of the WaveWatch in a real life environment.

A combination of a Heuristic survey and a Usefulness and Ease of Use Survey were used to investigate the utility of the WaveWatch within a real life office environment. Overall three main findings were ascertained through this process. Firstly, it was found that the WaveWatch was perceived by respondents to be easy to understand, unobtrusive, aesthetically pleasing and useful. These positive results were contrasted with a number of questions in the Usefulness and Ease of Use survey, where respondents were unsure if the WaveWatch was able to increase their on the job performance or allow them to complete tasks more quickly. Although respondents were unsure if the WaveWatch could increase their on the job performance in relation to effectiveness and task completion time, 60% of respondents found that the display could increase their productivity. In addition to these findings it was also found that the use of an ocean wave metaphor for real time information visualisation does have the capacity to be easily interpreted, with 80% of respondents agreeing that the WaveWatch was easy to understand.

As a related finding the use of a Heuristic survey and a Usefulness and Ease of Use survey proved to be a useful combination of exiting evaluation tools for evaluating the performance of an Ambient Information System in an office environment.

In conclusion a novel Ambient Information System, the WaveWatch was created through the novel combination of existing information technologies. It was found thorough the evaluation of the WaveWatch that respondents were able to easily understand the data that was presented though the ocean wave metaphor of the display. This result reveals the utility of such a metaphor for real time information visualisation. The use of three dimensional graphics on an Ambient Information System was also found to be technically feasible. In addition to these findings it was also determined that the display could have a positive effect on some areas of job performance, with 86% of respondents reiterating that they could find the display useful in relation to their job. In addition to these findings, a number of future research areas were also uncovered. These areas of potential future research are discussed below in section 6.2.

6.2 Future work

In addition to the primary findings that were ascertained through this thesis, a number of areas of potential future research were also found. The use of real time 3D rendering, more efficient methods for looping video, further research into definitions and taxonomies, the optimum number of metaphors utilized on an Ambient Display and the combination of visuals and sound on an Ambient Display all represent future research opportunities in the domain of Ambient Information Systems.

Each of these suggested avenues of future work were informed through a number of questions that became apparent during the design, implementation and evaluation stages of the WaveWatch Ambient Information System. The use of real time 3D rending for the generation of dynamic waves was found to be too difficult and time consuming at the beginning of the design phase. Although difficulties do exist around such a visualization technique, there is a possibility that the use of real time rendering could be a more ideal solution in comparison to the use of pre-rendered files, as the dynamics of an ocean could be more finely altered in real time to possibly better represent a data source.

Using real time rendering would eliminate the need to loop video files, which also represented a sizable challenge in creation the WaveWatch. Future research is required to determine a more efficient way to both loop and change videos seamlessly, in order to avoid a blank frame between the loading of each video.

In addition to these technical avenues of future work it was found in chapter two that there is no clear and consistent definition of Ambient Information Systems or the features that constitute them that are consistently used throughout the literature. Due to this it does become evident that more work is needed to create a universal language for Ambient Information Systems, further work around definitions in relation to the subtypes of Ambient Information Systems and the features that define such systems.

The final two areas of potential future work were found through analysing the responses to the Self-Completion Questionnaire. It was found that the majority of respondents (93.3%) agreed that the WaveWatch did not display too much information. In addition to this finding a number of respondents indicated that they would like to see the WaveWatch present more data or utilize another metaphor in addition to the dynamic ocean to allow the display of an additional data source. Although the low information capacity of the WaveWatch could have led to its perceived ease of use, further work is needed to determine the optimum number of information sources on an Ambient Information System, where a balance between aesthetics, information capacity and potential information overload need further investigation.

Finally, it was also suggested by a number of respondents that the inclusion of ambient sound could represent a positive inclusion for the WaveWatch. The combination of sound and visuals in an Ambient Information System does represent a future avenue of research. The use of a wave or ocean ambient soundscape is particularly intriguing due to the possible calming effects of ocean sounds, which could have the required attributes to be un-intrusive or ubiquitous within an office environment.

In conclusion there are a number of future research areas, which exist in relation to the domain of Ambient Information Systems. Future research opportunities were found during the creation of the WaveWatch that include the use of real time 3D rendering, the creation of more efficient methods for looping video, further research into definitions and taxonomies, further research into the optimum number of metaphors utilized on an Ambient Display and the combination of visuals and sound on an Ambient Display.

Appendix A – Self Completion Questionnaire & Human Ethics

Welcome

As you are aware this project is designed to determine the feasibility and effectiveness of an Ambient Information System called *WaveWatch* that uses an ocean wave metaphor for displaying real-time web traffic data.

Please answer the following questions in relation to the *WaveWatch* display that was installed into the Marketing and Public Relations office.

SECTION 1 – Background Questions

1. **Do you have any prior experience in user interface design?**

○ Yes ○ No

SECTION 2 – The WaveWatch Display

Please respond to each of the questions in relation to the WaveWatch display.

1. The information displayed on the WaveWatch display was relevant and useful.

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
◯	◯	◯	◯	◯

Do you have any other comments in relation to the relevance of the information presented on WaveWatch?

____

____

2. The WaveWatch display was obtrusive or interrupting

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
◯	◯	◯	◯	◯

Please explain why you found the WaveWatch display to be non-obtrusive, interrupting or otherwise.

____

____

3. The display attracted the attention of others

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
◯	◯	◯	◯	◯

How did the WaveWatch display attract your attention?

____

____

4. There was too much information displayed on the WaveWatch display.

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
○	○	○	○	○

Do you have any other comments in relation to the amount of data presented on the WaveWatch display?

____

____

5. I was able to easily understand the information conveyed through the WaveWatch display.

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
○	○	○	○	○

In what ways was the display either difficult or easy to understand?

____

____

6. I was able to understand the overall content of the display when glancing at it.

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
○	○	○	○	○

7. The WaveWatch display is aesthetically pleasing.

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
○	○	○	○	○

In what ways did you like the aesthetics of the display? How would you suggest that the aesthetics be improved?

____

____

Would you like to suggest how the aesthetics might be improved?

____

____

8. Other comments

Would you like make any other comments regarding the display?

____

____

SECTION 3 – Perceived Usefulness and Ease of Use

1. Using the display in my job would enable me to accomplish tasks more quickly.

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
◯	◯	◯	◯	◯

2. Using the display would improve my job performance

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
◯	◯	◯	◯	◯

3. Using the display in my job would increase my productivity.

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
◯	◯	◯	◯	◯

4. Using the display would enhance my effectiveness on the job.

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
◯	◯	◯	◯	◯

5. **Using the display would make it easier to do my job.**

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
◯	◯	◯	◯	◯

5. **I would find the display useful in my job.**

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
○	○	○	○	○

6. I found the WaveWatch display to be easy to use.

Do not agree	Some what disagree	Neither agree nor disagree	Somewhat agree	Completely agree
○	○	○	○	○

SECTION 4 – Further Comments

Please provide as much detail as you wish related to the following questions

What did you like most about the WaveWatch Display?

In what ways could the WaveWatch display be improved?

Chief Investigator: Dr Keith Nesbitt
School of Design, Communication and IT
ICT3.20
University of Newcastle, University Drive, Callaghan, NSW 2308.
Telephone: 4985 4519 Fax: 4921 5896
Email: Keith.Nesbitt@newcastle.edu.au

Information Statement for the Research Project:
***WaveWatch*: Evaluating an Ambient Information System**
Document Version 1; dated [25/03/14]

You are invited to participate in the research project identified above which is being conducted by Dr Keith Nesbitt, Senior Lecturer from the School of Design, Communication and IT at the University of Newcastle. The research is part of Ben Shelton's studies at the University of Newcastle, supervised by Keith Nesbitt from the of Design, Communication and IT.

Why is the research being done?
Ambient Information Systems are designed to be aesthetically pleasing displays of relevant, but non-critical information, that reside on the periphery of a user's attention. Unlike more traditional visualisations, such displays typically have limited interaction and are non-alarming. While the intention is to display useful, relevant information that changes over time, such displays are sometimes described as "Informative Art", recognising the importance of the aesthetic qualities such displays should have and also the way they might blend seamlessly into a work environment.

The purpose of this research is to determine the feasibility and effectiveness of an Ambient Information System called *WaveWatch* that uses an ocean wave metaphor to display real-time web traffic data. Live web traffic data from The University of Newcastle's website (http://www.newcastle.edu.au) will be used as a data source for the *WaveWatch* display.

Who can participate in the research?
The *WaveWatch* display will be installed in the Marketing and Public Relations (M&PR) office at The University of Newcastle. All staff members in the M&PR office will experience to the WaveWatch display, which will be presented on a large, wall-mounted television. The deployment of the display has been approved by Jacqui Reed.

After fifteen days staff members of The University's M&PR department will be invited to provide feedback about the display in an anonymous online survey. Participation is voluntary and no identifying information will be recorded of your participation. Participation requires about 20 minutes of your time to complete the survey.

What would you be asked to do?
If you agree to participate, you will simply need to complete the short online questionnaire. The results from this questionnaire will only be used to evaluate the usability and effectiveness of the *WaveWatch* display. The research Is not designed to collect information about work processes.

What choice do you have?

Participation in this research is entirely your choice. Whether or not you decide to participate, your decision will not disadvantage you. All participation is anonymous and no identifying information will be recorded.

How much time will it take?

The *WaveWatch* display will be installed in the M&PR office for two weeks before the evaluation. Despite the display existing in the M&PR office no effort from the user is required during this time, you may ignore or engage with the display as you wish. After this initial period participants will be offered the opportunity to complete a questionnaire, which will take approximately twenty minutes to complete.

What are the risks and benefits of participating?

There will be no direct benefit to you in participating in this research. By engaging with the display you may gain some incite to the web traffic during the display period. However the display is designed to be non-interrupting and the only effort required is to complete the survey if you choose to.

How will your privacy be protected?

All data collected will be non-identifiable. Data will be retained for a minimum of 5 years at the School of Design, Communication and IT and could be used in future ethically approved research. All data will be stored in a secure password-protected file by the Chief Investigator (Dr Keith Nesbitt).

How will the information collected be used?

The data will be reported in a thesis for Ben Shelton's Master of Information Technology (Advanced) degree and may be used for papers in scientific journals and conferences. This data could potentially be used in further research degrees. Participants are entitled to a summary of the results which will be made available to all staff in the area at the end of the project.

Non-identifiable data may be also be shared with other parties to encourage scientific scrutiny, and to contribute to further research and public knowledge, or as required by law.

What do you need to do to participate?

Please read this Information Statement and be sure you understand its contents before you participate in the evaluation. The survey for this is available at: https://www.surveymonkey.com/s/DNSXNQK

If there is anything you do not understand, or you have questions, contact the researcher.

Further information

If you would like further information please contact Dr Keith Nesbitt. Thank you for considering this invitation.

Dr Keith Nesbitt
Senior Lecturer
School of Design, Communication and IT

Ben Shelton
Master of Information Technology (Advanced) student
School of Design, Communication and IT

Signature

Keith Nesbitt

Complaints about this research

This project has been approved by the University's Human Research Ethics Committee, Approval No. H-2015-0213

Should you have concerns about your rights as a participant in this research, or you have a complaint about the manner in which the research is conducted, it may be given to the researcher, or, if an independent person is preferred, to the Human Research Ethics Officer, Research Office, The Chancellery, The University of Newcastle, University Drive, Callaghan NSW 2308, Australia, telephone (02) 49216333, email Human-Ethics@newcastle.edu.au.

Appendix B – Survey Results (Raw Data)

1. Do you have any prior experience in user interface design?

Yes	No
5	10

2. The information displayed on the WaveWatch display was relevant and useful.

Answer Option	Do not agree	Some what disagree	Neither agree or disagree	Somewhat agree	Completely Agree
Reponses	0	0	2	6	7

3. Do you have any other comments in relation to the relevance of the information presented on WaveWatch?

Responses
As the screen could not be seen from my desk, I only saw it when using the printer. Therefore it is hard for me to determine whether it was useful. (sorry)
It would've been good to recieve a scale at the start to know what the small waves vs. tsunamis are.
If you weren't directly informed that the wave represented the homepage views you wouldn't know what is was for.
It was really interesting to monitor as passing through the corridor. I often found myself checking and wondering about trends/time of day/what was contributing to wave.
It was very unobtrusive, which although it might be worth considering involving other senses like sound e.g. big wave crash only when significant result/need.
very interesting
It is an interesting concept worth pursuing further but it may need some adjustment to the translation of the information into the waves. I remember noticing a really big wave once in a while on a generally calm sea - perhaps a spike in data. It might have been better to have a 'feel' across a broader amount of time, for example, if there's more traffic across late afternoon, the sea would be in general more noticeably rougher in general in the late afternoon. I don't know what you did in preprocessing, but maybe the data could be a moving average instead of raw - or if it was a moving average, just making it broader.

4. The WaveWatch display was obtrusive or interrupting to your everyday work.

Answer Option	Do not agree	Some what disagree	Neither agree or disagree	Somewhat agree	Completely Agree
Reponses	13	1	0	1	0

5. Please explain why you found the WaveWatch display to be non-obtrusive, interrupting or otherwise.

Responses
Was easy to glance up at the screen and see the web traffic. Was not obtrusive in any way.
The display was not within my line of sight while positioned at my work area so I was not distracted or interrupted by it.
The wavewatch was great to have in the office.
The design wasn't harsh in colour or movement.
Very calming image, colours weren't too distracting
It was subtle, no noise, no jolting movement.
I was very interested in the display. It was magnificent to see information displayed in this manner! I enjoyed the theme, as I found it quite relaxing, enjoyable and informative to consume. FYI I don't associate these words as negatives. Maybe the existing environment / placement, number of senses used to absorbed and demographic of potential viewers etc. could be considered.
Partly because the information represented isn't like an 'alert' requiring immediate response (like an message coming in). Also it doesn't require any action to get the information (you don't need to click or do anything to check it). It's something you just notice once in a while so it really achieved it's 'ambient' goal (like 'ambient' music, it's in the background but interesting when you notice it.). The blue colour and wave motion are effective in that way too - there's no sudden or bright contrasts that would demand attention. The palm tree scene seems a little silly, but that's just me. I'd prefer something a bit more abstract.

6. The display attracted the attention of others.

Answer Option	**Do not agree**	**Some what disagree**	**Neither agree or disagree**	**Somewhat agree**	**Completely Agree**
Reponses	0	0	2	7	6

7. How did the WaveWatch display attract your attention?

Responses
I did get to see two big waves
When walking past the display location I would glance at the display to view the real time trend in web traffic.
It made me and stakeholders who entered the unit very interested in the traffic to the site and was a conversation starter!
The large waves attracted attention and generated much discussion about what time of day it was and the causes of high traffic volumes
Other departments who visited commented positively on the design and when they were told what it was representing they often asked if they could have a similar design installed in their offices. Very impressive.
When the large waves rolled in it would make you stop and watch
It generated conversation amongst staff who worked within the area
Beautiful colours and the subtle movement attracted me because I wanted to look at something aesthetically pleasing. It is something that soothes the senses to watch it for a little while.
It's movement.
People wanted to know what it was/symbolised.
Theme and movement of.
Regularly noticed the larger waves when walking past the display.
It was in a prominent place in the office, and was a new thing with an interesting, moving graphic. Also, because it's Ben's project we were talking about it and it's an interesting project.

8. There was too much information displayed on the WaveWatch display.

Answer Option	**Do not agree**	**Some what disagree**	**Neither agree or disagree**	**Somewhat agree**	**Completely Agree**
Reponses	11	3	1	0	0

9. Do you have any other comments in relation to the amount of data presented on the WaveWatch display?

Responses
I think the scale is a bit ambiguous because there is no information on what constitutes a small wave versus a large wave. I think it would be interesting for a viewer to be able to read some information (perhaps printed underneath the display screen) on how the scale was set and applied to the display to give the wave heights more relevance.
There would be good to have more data for each wave ie how many users it equates to, how long they have been on the homepage for etc.
Other elements - crabs, coconuts, surfer, breeze on the tree, etc - could be brought in to represent other web traffic elements. The design is flexible and would not be detracted from if further information was displayed.
It was interesting enough to watch with the single data source. But would be happy for other elements to represent other data sets.
Actually think we could display more. Sound was also identified as something that could be useful for people not in the direct line of site of the screen. This was because the waves evoke quite a calming sound.
I think I had the capacity to absorb more, but I'm very unsure if the effect would have been as enjoyable
Simple enough to be accessible, complex enough to be interesting.

10. I was able to easily understand the information conveyed through the WaveWatch display.

Answer Option	**Do not agree**	**Some what disagree**	**Neither agree or disagree**	**Somewhat agree**	**Completely Agree**
Reponses	0	2	1	5	7

11. In what ways was the display either difficult or easy to understand?

Responses
It is easy to see a trend in wave heights but without understanding the scale applied, it is difficult to extract any meaning other than a low or high flow of traffic.
It was easy and also generated excitement when the traffic was huge!
Graphics could be improved as in when there is a large tsunami the tree remained undisturbed.
Previous mentioned scale would better inform viewers on what traffic levels were coming through.
I found that unless the wave was explained to you , you would not know what it represented
The metaphor of the waves bigger being more visits was a really good visual cue. Super easy and with this audience, I think you could amp up the difficulty.
The size of waves relating to traffic was
Simple metaphor, easy to understand.
Wave was a simple metaphor to interpret
For me, I think it was easily to understand, I just found it lacked greater context.
Small waves = less traffic. Large waves = more traffic. Simple concept to grasp.
As mentioned before. While I understood that the 'roughness' of the sea was a representation of website traffic, and this seemed confirmed by the sea being visibly calmer at some times and there being a freak large wave once in a while, in general it was mostly about the same level of calm. Rather than calm with occasional spikes it should be more generally rougher and more generally smoother over broader periods of time. If the information is presented over short time spans, it takes more attention to absorb the information - so more spread out would be more ambient.

12. I was able to understand the overall content of the display when glancing at it.

Answer Option	**Do not agree**	**Some what disagree**	**Neither agree or disagree**	**Somewhat agree**	**Completely Agree**
Reponses	0	0	1	6	8

13. Did you notice any interesting patterns in the display that you would like to share?

Responses
There were always peaks at about 3pm in the afternoon.
Approx. midday and around 3pm daily the size of waves clearly demonstrated a large amount of traffic to the site.
Generally a fair bit of site traffic around 1pm.
Yes, I saw patterns of frequency and volume.
The larger waves in the morning and also around lunchtime - makes sense as lots of staff logging on in the morning and lots surfing the net at lunchtime!
There was an occasional very large wave. I didn't notice any overall patterns though. I wasn't in the office all the time though, so I might have noticed more patterns if I were in more regularly.

14. The WaveWatch display is aesthetically pleasing.

Answer Option	**Do not agree**	**Some what disagree**	**Neither agree or disagree**	**Somewhat agree**	**Completely Agree**
Reponses	0	0	1	6	8

15. In what ways did you like the aesthetics (look) of the display?

Responses
I liked the wave metaphor.
I personally, find blue calming.
The beach conveys a nice sense of relaxation
It was simple to understand!
Nice calming aesthetic
The wave concept was good
Colours, subtle movement and theme of the display all contributed to the pleasing aethestics of the display. Blue is really calming so fits in well with the idea of peripheral viewing.
It always had movement, but increases were noticeable with large waves.
It was clear in presenting data but also calming for office and nice use of colours
Very calming and enjoyable, a welcomed change to my busy and sometimes stressful role. The theme was very appropriate and something I could relate to quite easily.
Reminded me of a holiday/somewhere relaxing.
I like it's mild blue colour and the wave motion.

16. Would you like to suggest how the aesthetics might be improved?

Responses
I would like to see a wider landscape from a slightly more elevated point of view. This could allow you to show multiple consecutive waves as they approach the beach from the horizon, further highlighting the real time trend.
As mentioned, the functionality could be improved when there are large waves disturbing the sand/tree etc. There could also be more natural elements included so it is pleasing on the eye such as birds, crabs. But this is purely aesthetic and not of much relevance to the system.
Introduce sound and some other elements on the beach or in the water
It will look more sophisticated, the more complex the graphics are e.g clear water.
No - but further data inputs could be utilized with the same metaphor
I would have really liked to sound to occasionally accompany the display, as I feel it would have allowed me to absorb more information.
only thing I could think of would be white foam on the wave to make it slightly more realistic, but that is being picky.
The palm tree theme seemed a bit corny, but good for a prototype. I thought it would be better if it were more abstract. I think to be successful, since people have such divergent taste, you would need to provide a range of 'look and feel' options, to match people's taste, decor etc. Eg: I keep wanting the waves to be like the Joy Division poster. Some might like hep designer colour palette with floating squares, some might want a Hawaiian island, some might want want flocks of birds, psychedelic screen saver patterns, grey mist, business blue steel etc

17. Would you like make any other comments regarding the display?

Responses
Ambient audio would be a great addition.
A great tool for the office, would like to see it there more permanently.
An exceptional addition to the office that I would like to see more of. I was asked multiple times out of interest, what the display was. More often than not, they assumed it was communicating something and wanted to know more. A point of interest and gives the team something a little special to be proud of.
Great project. Great way to ensure team focus on analysis of our key communications channel.
Fantastic! Looking forward to further applications over time.
Awesome.
So to achieve the flexibility in look and feel you need to concentrate on clearly separating data, data preprocessing, and display, establishing an api, so you can plug any display into any data.

18. Using such a display in my job would enable me to accomplish tasks more quickly.

Answer Option	**Do not agree**	**Some what disagree**	**Neither agree or disagree**	**Somewhat agree**	**Completely Agree**
Reponses	1	1	8	5	0

19. Using such a display could improve my job performance.

Answer Option	**Do not agree**	**Some what disagree**	**Neither agree or disagree**	**Somewhat agree**	**Completely Agree**
Reponses	1	0	3	11	0

20. Using such a display in my job could increase my productivity.

Answer Option	**Do not agree**	**Some what disagree**	**Neither agree or disagree**	**Somewhat agree**	**Completely Agree**
Reponses	1	0	5	9	0

21. Using such a display could enhance my effectiveness on the job.

Answer Option	**Do not agree**	**Some what disagree**	**Neither agree or disagree**	**Somewhat agree**	**Completely Agree**
Reponses	1	0	7	7	0

22. Using such a display could make it easier to do my job.

Answer Option	**Do not agree**	**Some what disagree**	**Neither agree or disagree**	**Somewhat agree**	**Completely Agree**
Reponses	0	1	5	8	1

23. I would find this type of display useful in my job.

Answer Option	**Do not agree**	**Some what disagree**	**Neither agree or disagree**	**Somewhat agree**	**Completely Agree**
Reponses	0	0	2	9	4

24. I found the WaveWatch display to be easy to use.

Answer Option	**Do not agree**	**Some what disagree**	**Neither agree or disagree**	**Somewhat agree**	**Completely Agree**
Reponses	0	0	1	6	8

25. What did you like most about the WaveWatch Display?

Responses
It is relaxing to watch and unobtrusive
Simple and makes you conscience of the web traffic. Makes the abstract more tangle, and makes you more aware of the impact of what you are doing.
Monitoring it and attributing it to peak times. Then monitoring my own data to see if it translated across.
- that is was relevant to our area of work - gave us something special to be proud of / a point of interest in our office
Made me feel like I knew when something big was happening on our website.
The 'ambient' element - it was there but not confronting. It would make you aware of trends and follow up when something of noticeable difference.
The unobtrusive, but clear, representation of a single metric made it easy to absorb at a glance.
The theme and how soothing it was. It was such a pleasurable way to consume information.
It's a very clever concept - conveying lots of information but in a simple, easy to digest way. Constantly changing. Makes you think about what's happening on the web site.
It's a great idea, and it achieves it's objective - it had the right balance of being occassionaly noticeable without being distracting to be truly 'ambient'. I'd like to have something like that around, and it would be quite useful if the differences were a bit clearer. It would be good if you could walk into the office, or turn around and see it once in a while and say, "Hey, the traffic's unusually rough this afternoon. I wonder why?" Then you might pick up on things you wouldn't otherwise notice. Like your marketing campaign is successful, or someone at a conference was talking about you and it sparked a lot of tweets, or a government announcement changed the market and sales increased or whatever.

26. In what ways could the WaveWatch display be improved?

Responses
I think an audio component and a wider point of view would improve the experience.
Nothing other that what I have already mentioned.
- should be a long term installation - additional of elements that represent more/other information
More data inputs.
Refinement of the visuals, for example, the less "computer generated" that the waves look potentially the better the display blends in the background environment.
Sound or amplify the number of senses needed to used / interpret information. And size of display and placement of. I would potentially like to see a mini version on my desk or within my personal environment e.g. my pc etc.
n/a
I've already mentioned possible improvements. Mainly: - The differences in 'roughness' could be more obvious and cover broader amounts of time. - There's a lot of potential for different aesthetics to be implemented.

Appendix C – Survey Paper

The Aesthetic Awareness Display – a New Design Pattern for Ambient Information Systems

Ben Shelton
University of Newcastle
Callaghan, 2308,
NSW, Australia
Ben.Shelton@newcastle.edu.au

Keith Nesbitt
University of Newcastle
Callaghan, 2308,
NSW, Australia
+61 (02) 49854519
Keith.Nesbitt@newcastle.edu.au

ABSTRACT
Ambient Information Systems are designed as everyday, peripheral information sources that visualise useful data in a way that can be attended to when possible. Importantly these displays need to be design to seamlessly fit into their environment and should not interrupt an individual from their primary task. The first Ambient Information System, known as the "Dangling String" was described in the literature in 1996. Since this time a number of different systems have been reported. In this paper we re-examine the concepts, definitions and background to this field that have developed over the last 20 years. This includes a detailed discussion on the key design features or dimensions that have been used to help categorise and evaluate such displays. We also examine 36 previously reported Ambient Information Systems and categorise them in terms of an existing taxonomy of design patterns for such systems. This helps us identify an underutilised design area for these displays and leads us to propose a new design pattern, known as the "Aesthetic Awareness Display" to assist in the design of these systems. This type of Ambient Display uses metaphors in order to encode a few data elements into an aesthetically pleasing display with the goal of raising general awareness about the data.

Categories and Subject Descriptors
User interface design, Visualization design and evaluation methods, Ubiquitous computing

Keywords
Ambient Information Systems; Ambient Displays; Design patterns; Informative Art, Calm Computing

1. INTRODUCTION
In our everyday life we constantly receive ambient information from our environment. This occurs through a range of mediums such as sound, light, temperature and air movement. For example, we can receive information such as the time of day through the amount of light shinning through a window, the time to wake up in the morning from birds tweeting, the running condition of an air conditioner by the quality of sound it emits or even the degree of excitement at a party from the chaotic din of background noise.

These "natural" ambient information sources generally sit in the periphery of an individual's attention. However, it also possible for a person to redirect attention to such peripheral information sources and focus more carefully on their content. This phenomenon is well known in visual information processing where the majority of the visual scene resides at the periphery of attention providing context to a much smaller focus of attention [13]. Uninteresting information sources such as a tree branch brushing against a window-pane might be ignored by an individual in preference for some other more critical and primary information source. However, attention can swiftly be directed to an alternative location if startling stimuli, such as sudden unexpected motion or rapid changes in light alert the individual to potentially valuable information in the periphery [46].
The "Cocktail Party Effect" [41] illustrates a similar phenomenon of selective attention in the auditory domain. This effect uses the analogy of a cocktail party, to highlight the ability of an individual to focus their listening attention on a single conversational source in a crowd of conversations [41]. For example, a background conversation where the individuals name is suddenly used.
While these ambient information sources are an abundant part of our natural environment they are less prevalent in our technological environments. Rather than sitting calmly in the periphery, traditional digital devices such as mobile phones, pagers and web browsers have been described as the enemy of calm [52]. This is due to their ability to demand immediate attention from the user.

Opposed to these interrupting, information devices is the notion of *Calm Technology* [52] that aims to deliver information by devices in an individual's periphery. A carefully designed, "calm" or non-alerting display situated in one's periphery, can provide a user with information in a similar way to natural ambient displays. Such digital devices that deliver information while residing in an individual's periphery are often referred to as *Ambient Information Systems* or *Ambient Displays*.
A typical definition of such systems is: *"Ambient displays are abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user's attention"* [24]. Ambient Information Systems have also described by some authors as Peripheral Displays, or "*displays that show information that a person is aware of, but not focused on*" [25]. A number of alternative definitions are provided in Table 1. While these definitions have similarities there is no uniformly accepted definition of Ambient Information Systems. Thus the first role of this survey paper is to highlight and compare the key features of Ambient Displays provided by various definitions. When we examine around 20 years of previous work in this field we also identify a wide variety of displays, each utilising different media and a range of data sources. Thus a further aim of this survey is to re-examine previous work in this field, particularly in relation to the various design dimensions, categorisations or taxonomies that have been described in this field. We also consider some 36 different displays that have been reported and categorise them in terms of a pre-existing taxonomy of design patterns for Ambient Information Systems [42]. This analysis of previous systems allows us to identify a new design pattern, which we describe as an Aesthetic Awareness Display and discuss in section 5. Finally we conclude by identifying outstanding gaps in this field that still require further research.

Table 1. Various definitions for Ambient Information Sources

Definition	Ref
"ubiquitous computing devices which monitor and display information in a peripheral, non- obtrusive way, and are meant to reduce demand on one's memory and overloaded senses"	[2]
"Ambient displays are abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user's attention."	[24]
"An ambient display resides in the periphery of a person's attention. The display calmly changes state in some way to reflect changes in the underlying information it is representing"	[49]
"computer augmented, or amplified, works of art that not only are aesthetical objects but also information displays, in as much as they dynamically reflect information about their environment"	[44]

2. AMBIENT INFORMATION SYSTEMS

Many different displays have been developed since 1996 [52] that can be categorised as Ambient Information Systems. These include Informative Art displays [44], Digital Family Portraits (Mynatt et al., 2001), Ambient Mirrors [31], Tangible Bits [18], Invisible Displays [39] and Virtual Paintings [48].

An early example of an Ambient Information System is the ambientROOM [19]. The ambientROOM was designed to provide information to the user for background processing through a range of ambient mediums such as light, sound, motion and airflow. One example of an Ambient Information System that was installed into the ambientROOM is Water Ripples. Water Ripples reflected shadows of water on the roof of the ambientROOM. The ripples of the water were controlled by a hamster, if the hamster ran in its wheel the water ripples on the roof would vibrate and therefore visualise the activities of the nearby animal.

Another example of an Ambient Information System is the Informative Art display that aimed to visualise bus departures in real time [48] The display that was inspired by the art of Mondrian, visualised the movements of buses by manipulating a piece of art on an LCD screen. Each coloured square that made up the piece of Informative Art represented a bus, the size of each square would change in real time to represent the amount of time before a bus would leave a particular bus stop.
The Digital Family Portrait, another prominent display from the literature [31] which took the form of a photo frame that was also capable of delivering information to the user. The aim of the project was to create a device that could help the family members of an elderly individual become more aware of their elderly relative's activities, health and well being. Information about the elderly individual

was visualised through a series of icons on the frame that would represent a range of metrics relating to their wellbeing. Such a system might be advantageous in relaying information to a family member that is some distance from their elderly relative.
These previous examples help to highlight some key features captured in various definitions for Ambient Displays (see Table 1). Namely, that such displays focus on displaying information in the periphery though novel means with an additional concern for producing an aesthetically pleasing display. These previous examples also demonstrate the diversity of such displays, a diversity that lends itself to further consideration. In the remainder of this section we look more closely at some of the clear distinctions that occur between these diverse Ambient Displays.

2.1 Tangible versus screen-based displays

The designs of Ambient Information Systems often differ from one another in relation to a number of physical design features. Most notable of these design considerations is the physical form of the display itself. Indeed two trends that have developed include the manipulation of a tangible-object for display versus a more traditional screen-based display.

Tangible Ambient Information Systems describe displays that utilise physical media in order to deliver peripheral information to the user. One of the first Ambient Displays, referred to as the Dangling String [52] or Live Wire has been cited as being the root of all Ambient Displays [28]. Dangling String was an Ambient Information System created by artist Natalie Jeremijenko which comprised of an 8-foot piece of plastic spaghetti that hung from the celling [52]. The Display, which used the physical medium of a moving string as well as the sound it emitted, was used to notify individuals of network traffic. There are many other examples throughout the literature particularly in relation to Tangible User Interfaces [19]. These displays are also sometimes referred to as Sculptural Displays [42].

Sculptural Displays usually have limited modalities for expressing information and this usually display a single targeted piece of information [42]. Examples include “Show-me” [21] and The Power-aware Cord [15]. Both of these Ambient Information Systems aim to increase the awareness of a single metric to the user though sculptural changes to a tangible object. In the case of “Show-Me” real time water usage information is presented to the user through a series of LED lights. The Power-aware cord displays power consumption of a particular appliance by adjusting the brightness of a glowing cord.

An alternative group of Ambient Displays can be distinguished by their common use of LCD screen technology to deliver Ambient Media. While the use of an LCD display may seem contradictory to the concepts of Calm Computing, many of the displays that utilise an LCD display identity as being Ambient Art [44]. Such art displays can be integrated into any environment where wall art is commonly used [44]. Ambient Art does find itself suited to the use of LCD displays for information transmission due to the concept’s focus on mapping layers of information onto existing pieces of art typically pictures or posters [44].
One such example that demonstrates the typical attributes of a screen based display but is also considered a piece of Ambient Art is the Butterfly/Dragonfly display [34].
Butterfly/Dragonfly is an Ambient Information system that displays Australian Stock Exchange data in the periphery through the metaphor of Ambient Art. The display utilises the placement of butterfly and dragonfly symbols in order to visualise information about stock prices. The display is made ambient by placing the screen in a picture frame and then deploying it in a private office environment where similar artwork is present.

A potential advantage of screen-based displays over their more sculptural counterparts, is the ability for designers to adopt more complex information mappings or metaphors that can display multiple information sources. One such example of a screen based display that conveys multiple metrics to a user tin this way is the MoneyTree [10] display. MoneyTree presents real time information about stock prices and volumes to the user on a screen based display using a tree metaphor.

2.2 Levels of Ambience

Another differentiating feature in the literature is the level of ambience or user interaction required for different Ambient Information Systems. In terms of interaction there are displays that require no direct input from the user in order to function or to be useful. These displays represent the purest form of Ambient Information Systems in that they act solely as a peripheral device to deliver information. The purposeful lack of interaction is a design feature of such fully Ambient Information System. In these cases, the emphasis is on creating a peripheral device that requires no interaction from the user. Such displays embody the concepts of Calm Computing, where a device avoids becoming the “enemy of calm” [52] by alarming or demanding input from the user.

Exemplifying these fully Ambient Displays where no interaction is required is the Mondrian bus display [48]. The display developed by Skog, Ljungblad & Holmquist is used to convey the movement of buses by modifying a piece of existing Mondrian art in order to create an Informative Art display. The display is fully ambient due as no direct input is required from the user to utilise the display. While the display is context-dependent, representing information about relevant bus arrivals, it can be used by simply glancing at the display where it resides within its public environment.

The majority of displays reported in the literature aim to be purely peripheral with no interaction required from the user. By contrast with these fully Ambient Displays are occasional displays that require or intentionally enable some form of interaction. These more interactive types of display can be classified as being Semi-Ambient. These displays differ to their fully ambient counterparts in that while they do deliver information through the periphery they require direct purposeful input from the user to fully function, or at least become more useful and relevant when such interaction occurs.

One typical example of a semi-ambient display is the LumiTouch system [5]. The LumiTouch is a communication device in the form of a photo frame the can be used to communicate with another individual who has a LumiTouch Display. The LumiTouch incorporates interaction through a series of touch sensors along the front of the frame that can be pressed by the user. Such touch interactions are communicated to the other paired LumiTouch display to create communication between two individuals. While there are other possible methods of communication through the LumiTouch that do not require such direct interaction, it is clear that during such an interaction with a touch sensor it is no longer ambient or in the user’s periphery for an extended period of time. This purposeful removal of the display from the periphery to centre of a user’s attention in order to provide input differentiates such a display from a fully ambient display.

In reviewing the key features and definitions of Ambient Information Systems it is evident that such displays can differentiated by physical form, either being more sculptural physical objects or utilising more traditional screen-based display technologies. Another differentiating characteristic is the level of ambience or interaction required for the display. However, the key design features that classify the various Ambient Displays are not consistently reported in existing literature. Given the range of such displays and the importance of defining the key design dimensions of Ambient Information Systems we now examine the previous taxonomies (see table 2) that have attempted to better classify the design dimensions of these systems.

Table 2. Previous design dimensions suggested for classifying Ambient Information Systems

Design Dimensions	Number of Dimensions	Year	Ref
Intrusiveness, Notification, Persistence, Temporal context, Overview to detail, Modality, Level of abstraction, Interactivity, location, Content and aesthetics	11	2002	[2]
Interruption, Reaction, Comprehension	3	2003	[26]
Personalized, Flexible, Consolidated, Accurate, Appealing	5	2004	[49]
Abstract, Non-intrusive, Public, Aesthetic	4	2005	[20]
Information Capacity, Notification Level, Representational Fidelity, Aesthetic Emphasis	4	2006	[42]
Distraction, Comprehension,	4	2007	[34]

Usefulness, Interoperability			
Abstraction level, transition, notification level, temporal gradient	9	2007	[50]
Abstract, Playful, Attractive	3	2010	[45]

3. DESIGN DIMENSIONS

A broad range of Ambient Information Systems and their characteristics were discussed in the previous section. Given this broad range of systems it is not surprising that further classifications of these systems has been proposed [27], [26], [42].

The intention of these more detailed classifications is to help understand the design space of Ambient Information Systems and so allow for better comparative analysis of the various types of systems. More formal design dimensions can assist in answering two key research questions, namely "How to design a good ambient display?" and "When is an ambient display good?" [34]. While these questions are simple in their premise there are numerous attempts throughout the literature to define the specific design attributes that are required in order to create a "good" Ambient Information System. Many authors discuss ideal design dimensions and some formative examples of these dimensions for classifying Ambient Information Systems are summarised in Table 2. In the rest of this section we examine in detail four formal frameworks that have been created to help categorise Ambient Information Systems and highlight the similarities and differences of each.

3.1 Early Design Dimensions

The Ames and Dev design dimensions provide one of the earliest, and examples of a design taxonomy for Ambient Information Systems [2]. This taxonomy consisted of eleven distinct design dimensions (see table 3 for a description of these dimensions).

Table 3. Ames and Dey's early design dimensions [2]

Design Dimension	Description
Intrusiveness	Ambient Information Systems do not require constant attention from the user but convey information with differing levels of intrusiveness dependent on the significance of the data.
Notification	Displays can move from the periphery to the centre of the user's attention when required. Changes in information are conveyed subtly to the user.
Persistence	Information is shown on the display using an appropriate time scale and refresh rate.
Temporal Context	Contextual information is provided by the display if comparisons with past or predictions of future information are present.
Overview to detail	Displays show sufficient information in order for the user to gather knowledge at a glance. More detail is provided to the user if they pay attention
Modality	Displays provide information through a sensory channel that is not already overloaded
Level of abstraction	Information is conveyed through an abstract or indirect manner. The display's visualisation should be related to the nature of the information.
Interactivity	Displays employ an appropriate level of user interaction, without being overall demanding on the part of the user.
Location	The design of such a display addresses the location in which it will be installed.
Content	Displays convey information that users care about.

Dimensions such as "Intrusiveness", "Notification", "Interactivity", "Location" and "Content" describe attributes that commonly occur in the various definitions for Ambient Information Systems (see Table 1). The Ames and Dey taxonomy also includes concepts directly related to Calm Technology and User Interface Design evaluation. For example, emphasis is put on Intrusiveness and Notification in relation to such displays being non-alarming, which is a key concern of Calm Technology. Furthermore, several of the design dimensions such as Temporal Context, Overview of details and Content are similar to some of Nielson's usability heuristics [37].Many of the eleven Ames and Dey design dimensions also overlap with the reported design goals of previous systems. For example, the design motivations given for the Breakaway display were noted as being abstract, non-intrusive, public and aesthetic [20].

3.2 Peripheral Display Dimensions

While the Ames and Dev taxonomy includes the dimension of Intrusiveness and Overview to detail they do not focus directly on a key aspect of Ambient Information Systems, namely that they sit on the periphery of attention. A further taxonomy was derived to help categorise the design of Peripheral Displays and this was subsequently integrated into a Peripheral Display Toolkit [25]. This taxonomy focused on cognitive psychology models of attention. It divided this key concept of attention into four main states: preattention, inattention, divided attention, and focused attention. Stimuli attended to in the early preattentive phase are processed without contextual reference, go unnoticed and as such do not affect the viewer's perception. By contrast during the inattention state, perceptual stimuli may affect behaviour even though they are processed subconsciously. The final two states, divided attention and focused attention, relate to perceived stimuli that are processed consciously and used either in multi-tasking fashion or a more singular focused task.

This taxonomy uses three dimensions, namely Notification Level, Transition and Abstraction to classify Peripheral Displays. In this taxonomy, Abstraction refers to way incoming data is transformed to meet the requirements of the output device [25]. It defines two distinct types of data abstraction used in displays, either degradation or feature extraction. Degradation involves ignoring some original data or reducing the fidelity of the data in some other way. Feature extraction concerns the refinement of data or derivation of new measures from the underlying data. This *abstraction* dimension might be described as the data mapping part of design for Ambient Information Systems and is a common step in Information Visualisation process [33].

In this taxonomy the *Notification Level* of the incoming data is further used to define the display and can be described as "demand action", "interrupt", "make aware", "change blind", and "ignore" [26]. A "demand action" notification requires that the user perform some action to stop the alerting, thus requiring the refocus of a user's primary attention to respond. An "interrupt" is of slightly lower priority and is characterized as an attempt to obtain the user's focused attention. The "make aware" data is of slightly lower priority but like the "interrupt" class of data will signify the need for divided attention from the user. The "change blind" corresponds to inattention, and as such should attempt to not distract the user's conscious primary attention. Finally, the "ignore" category represents data that should not be displayed, and should not correspond to any attention level.

Ambient Information Systems are peripheral displays that fall into the "make aware" notification level. Only very critical information would require the user to be alerted, to drop everything and attend to the displayed information. This is not in general the design goal of ambient displays. It does imply that Ambient Information Systems could change notification level based on the changes to incoming data over time. The lower notification levels correspond to less critical data and thus should be displayed in a manner that does not allow peripheral changes in the display to distract the user's attention away from their primary task.

The third part of this taxonomy describes the *Transitions,* such as fading or movement that are used to update the states of the information display. These should be designed to attract an appropriate amount of attention on the basis of the notification level of the underlying data, the sensory modality of the display and taking into account context such as the background noise in area of the display. Abrupt transitions can be used for their alerting function when changes "demand action" or are designed to "interrupt". By contrast "minimally attended" displays such as those seen in Ambient Information Systems with "make aware" and "change blind" notifications should adopt subtler or repetitive transitions that are just noticeable but not distracting.

As can be seen from this discussion the Notification, Transition and Abstraction taxonomy while applicable to Ambient Information Systems also includes many additional displays that while peripheral are designed to act as alarms or to have alerting functionality. In these cases, the underlying data may even be categorized as critical to some divided attention task and as such displays might be more carefully designed to allow monitoring rather than having the vague goal of awareness that is described for many Ambient Information Systems. This monitoring is arguably outside the intended functionality of Ambient Information Systems.

One further noticeable shortcoming in this taxonomy for Ambient Information Systems is the decision to not include aesthetics as a dimension. Generally aesthetics is seen as an important design goal for Ambient Information Systems.

3.3 Interruption, Reaction, Comprehension

Another taxonomy that includes Ambient Information Systems is based on a review of typical user goals and constraints for notification systems [27] *Notification systems* are defined *"as interfaces that are typically used in a divided-attention, multitasking situation, attempting to deliver current, valued information through a variety of platforms and modes in an efficient and effective manner"* [27].

This categorization by McCrickard [27] has foundations in theories related to human information processing and was devised to provide an unifying model that can be used to guide evaluation for such notification systems. The taxonomy is based on the three dimensions of interruption, reaction, and comprehension. These dimensions are considered critical in interfaces designed to support divided attention or multi-tasking by users when monitoring real-time data [27].

Interruption refers to the expected level of distraction or intrusion required from some primary task to events in the background-monitoring task. Reaction refers to speed and accuracy of response expected to a given interrupting stimulus. Comprehension refers to the design criteria that assist remembering and allows the user to make sense of patterns in the display. Each of these three dimensions is rated on a scale from low (0) to high (1). Considering the maximum and minimum values of these three dimensions allows for the definition of eight idealised models or design patterns (see table 4).
For example, in this taxonomy Ambient Information Systems would be specified with a low level of Interruption, a low expectation for the user to react quickly and accurately but have a high level of comprehension or memorability so that any patterns can be recalled and processed at a later time. By contrast Alarms and Critical Information Monitors would be expected to have both a high interruption and level of reaction specified as part of their design goals.

Table 4. General models used to categorise Notification Systems [27]

Display Type	Interruption	Reaction	Comprehension
Noise	0	0	0
Ambient Media	0	0	1
Indicator	0	1	0
Secondary Display	0	1	1
Diversion	1	0	0
Information Exhibit	1	0	1
Alarm	1	1	0
Critical Activity Monitor	1	1	1

Once again this taxonomy covers a broader range of systems of which Ambient Information Systems covers a smaller part. It has the benefit of suggesting a cognitive process model that allows for design specification in terms of user goals and interaction constraints such as context, information complexity and cognitive workload. It also supports comparative evaluation studies to be carried out for systems that can be defined in terms of the three dimensions that make up the framework. However, like the framework for Peripheral Displays it explicitly excludes key criteria of Ambient Information Systems such as aesthetics and subjective satisfaction or enjoyment as primary dimensions [27]. A taxonomy more specific to Ambient Information Systems is discussed next.

3.4 Capacity, Notification, Representational Fidelity and Capacity

Probably, the most well known classification of Ambient Information Systems in the literature defines four key dimensions that can to use help categorize these systems. These four design dimensions are: Information Capacity, Notification Level, Representational Fidelity, and Aesthetic Emphasis [42]. Pousman & Stasko's taxonomy is effective in that it not only defines a specific set of design dimensions, but also allows each of these dimensions to be given an ordinal ranking (from low to high). Thus any particular Ambient Information System can be ranked on each dimension by choosing from the five categories of low, somewhat low, medium, somewhat high and high (see table 5).

In this taxonomy, Information Capacity relates to the number of information sources that an Ambient Information System can visualise at any one time. For example, a display that only displays one data element would receive a ranking of low for Information Capacity, while a display that encodes twenty or more data elements would receive a ranking of high.

Table 5. Mappings Notification level and Representational Fidelity design dimensions [42]

Level	Notification level	Representational Fidelity
High	Demand Attention	Indexical – Maps Photographs
Somewhat High	Interrupt	Iconic – Drawings, doodles
Medium	Make aware	Iconic - Metaphors
Somewhat low	Change blind	Symbolic – Letters and numbers
Low	Ignore	Symbolic – Abstract symbols

Notification level represents the level to which an Ambient Information System can alert or interrupt a user. For this dimension the five categories can be understood as Ignore (low), Change blind (somewhat low), Make aware (medium), Interrupt (somewhat high) and Demand Attention (high). For example, a display such as the Water Lamp would have a low level of notification due to its ability to not interrupt the user unnecessarily through its use of subtle light and shadows to convey data [53]. On the other end of the spectrum a display such as Mobile Bus could be rated as having a somewhat high level of notification due to its use of movement that could easily attract the attention of an individual [24].

Representational fidelity describes how an Ambient Information System encodes the data it displays. This can range from very realistic representations using photographs or cartographic maps to the quite abstract use of symbols to represent the underlying data. For this dimension the five categories can be specified as symbolic - abstract symbols (low), symbolic – letters and numbers (somewhat low), iconic – metaphors (medium), iconic – drawings, doodles, (somewhat high) and indexical – maps and photographs (high). Examples exist throughout the literature of differing implementations of representational fidelity. A display such as the Information Percolator would have a low level of Representational fidelity due to its use of abstract symbols (bubbles) to convey data to the user [16]. The bus mobile is an example of a display that could be classified as having somewhat low representational fidelity due to its use of letters and numbers in order to deliver contextual information to the user [9]. The Butterfly/Dragonfly display uses the metaphor of a butterfly being positive and a dragonfly being negative in order to deliver information to the user [34], giving it a representation fidelity classification of medium due to its reliance on metaphors for information transmission. The InfoCanvas display is capable of exemplifying both somewhat high and high levels of representational fidelity through its ability to convey information through icons as well as photographs [49].

Aesthetic Emphasis, the final axis of this taxonomy represents the level of effort to which a display aims to be an aesthetic rather than simply a functional object. Once again, the categories of low, somewhat low, medium, somewhat high and high are used to position displays on this dimension. The measure is intended to relate to the designer's intention rather than being some absolute measure of a display's aesthetic worth. A display such as InfoPulse could be classified as having a low level of aesthetic emphasis due to its design not being overly focused on aesthetics [29]. Representing the opposite end of the scale, Informative Art displays such Butterfly/Dragonfly [34] have high levels of Aesthetic Emphasis due the levels of design effort put into making the display not only convey information but also be an aesthetic object.

The Pousman & Stasko's taxonomy has many overlaps with other taxonomies in terms of its design dimensions. However, it remains one of the best-known classifications specifically described for Ambient Information Systems. Arguably one of reasons it is well known in the field is the identification of various design patterns based on the four dimensions. In the next section we briefly review the concept of a design pattern before describing the original design patterns that were first used to classify Ambient Information Systems [42]. We will then extend this previous work by categorising Ambient Information Systems into these design patterns and then by updating the original work of Pousman & Stasko [42]. This process will help us identify a new design pattern based on this taxonomy that will be described in section 5.

4. DESIGN PATTERNS

One way to solve common design problems is to adopt, or adapt, a solution that has been useful in the past. This is true of Ambient Information Systems as it is in other design domains. Design patterns are intended as a more formal way of capturing good designs, or design practices, so they can be reused. They also help categorise designs to allow better comparison on various design features.

The approach of using formal design patterns is attributed to Christopher Alexander who described over 250 problems in architecture along with descriptions and solutions [1]. These problems and solutions together formed a "pattern language" for communicating good design practice. In architecture, such design patterns were identified at many scales and were frequently applied together to solve specific design problems. The second community to broadly adopt the notion of design patterns was the Object-oriented software industry where it has been extensively used [14]. The approach has also been described in other design domains such as auditory display design [3], computer game design [36] and even the more general field of creativity [35].

Based on the design dimensions of their taxonomy, Pousman & Stasko [42] used this approach to describe four particular design patterns that captured existing Ambient Information Systems. The four design patterns were known as; Sculptural Symbolic Displays (table 6), Multiple Information Consolidators (table 7), Information Monitor Displays (table 8) and High Throughput Textual Displays (table 9).

Symbolic Sculptural Displays are displays that typically display a single metric to the user through sculptural means [42]. A good example of a Symbolic Sculptural display is the Dangling String [52] See table 10 for more examples of this design pattern.

Multiple Information Consolidators are displays that are able to deliver many pieces of information to the user. Displays that are considered as being Multiple Information Consolidators are typically screen based as this allows multiple data sources to be integrated into the display design. The InfoCanvas [49] is a good example of this type of display. See table 11 for more examples of this design pattern.

Information Monitor displays are Ambient Information Systems that are displayed as part of a user's desktop computer environment and might be considered by some to fall outside the novel types of media or integrated environmental displays more typically associated with Ambient Information Systems. The High Throughput Textual Display constitutes a display that uses simple graphics such as icons or text in order to deliver information to the user. Throughput Textual Display's are capable of conveying many metrics to the user but have little focus on aesthetics, again placing them somewhat outside more typical Ambient Information Systems

Table 6. Design Dimension mappings for the Sculptural Symbolic Display design pattern [42]

Symbolic Sculptural Display	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
High				
Somewhat high				X
Medium				
Somewhat low		X		
Low	X		X	

Table 7. Design Dimension mappings for the Multiple Information Consolidator pattern [42]

Multiple Information Consolidator	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
High	■		■	
Somewhat high				
Medium		■		■
Somewhat low				
Low				

Table 8. Design Dimension mappings for the Information Monitor Display pattern [42]

Information Monitor Display	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
High		■		
Somewhat high	■			
Medium			■	
Somewhat low				■
Low				

Table 9. Design Dimension mappings for the High-Throughput Textual pattern [42]

High-Throughput Textual Display	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
High	■			
Somewhat high				
Medium				
Somewhat low		■	■	
Low				■

Table 10. Examples of Sculptural Symbolic Displays

			Ranking 1 (low) …. 5 (high)			
Display	**Reference**	**Year**	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
Dangling String	[52]	1996	1	2	1	4
Water Lamp	[8]	1998	1	2	1	4
Pinwheels	[8]	1998	1	2	1	4
LumiTouch	[5]	2001	1	2	1	4
Power-Aware Cord	[15]	2005	1	2	1	4
Tea Place	[23]	2007	1	2	1	4
Follow the lights	[45]	2010	1	2	1	4
The Clouds	[45]	2010	1	1	1	4
Show me	[21]	2009	1	3	3	4
Breakaway	[20]	2005	1	2	3	4
MoveLamp	[11]	2013	1	2	3	4
PlantDisplay	[22]	2006	1	1	3	4
CareNet	[6]	2004	2	2	1	4
Information Percolator	[16]	1999	2	2	1	4
Digital Family Portrait	[31]	2001	2	2	1	4
Hello.Wall	[43]	2003	2	2	1	4
Bus Mobile	[9]	2003	2	4	1	1
Nimio	[4]	2005	1	2	1	4
Ambient Orb	[7]	2015	1	2	1	4

In the remainder of this section we re-examine existing Ambient Information Systems in terms of these four design patterns (see table 10). We do this by subjectively ranking Ambient Information Systems from the literature on each axis of the Pousman and Stasko taxonomy. The design dimensions are subjectively ranked in categories from one to five (1 for low, 2 for somewhat low, 3 for medium, 4 for somewhat high and 5 for high).

The displays reported in table 10 embody the design features of Sculptural Symbolic Displays in that they all have a high level of aesthetic emphasis but low levels of information capacity and notification. Furthermore all the displays in table 10 are tangible, aesthetic objects as has been previously suggested for this design type [42].

By contrast, the displays in table 11 can been classified as Multiple Information Consolidators as they try to convey many metrics to the user through a display that is moderately concerned with aesthetics. Each of the displays that fall under this design dimension are screen-based. This suggests the utility of such screen-based displays to convey many data elements to the user.

While there are a large number of displays that fit the first two design patterns there is a lack of reported displays related to Ambient Information Systems that exemplify the design attributes of the Information Monitor and High-Throughput Textual design patterns. While these types of displays do exist they may more generally be reported outside the domain of Ambient Information Systems.

Table 11. Examples of Multiple Information Consolidators

			Ranking 1 (low) …. 5 (high)			
Display	**Reference**	**Year**	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
InfoCanvas	[49]	2001	5	3	3	3
Ambient Calendar	[40]	2008	5	3	3	3
Exercise Awareness Display	[12]	2008	4	3	3	3
Ambient News	[51]	2010	5	3	2/3	3
Research Wave	[17]	2010	5	3	2/3	3
Time Management	[38]	2011	4	3	1	3

5. AESTHETIC AWARENESS DISPLAY

In reviewing the literature and ranking existing Ambient Information Systems it is apparent that a number of systems do not fit either of the four design patterns described by Pousman & Stasko [42]. However, these Ambient Information Systems, (listed in table 12) all hold similar attributes when ranked against the axes of Pousman & Stasko's taxonomy. The displays covey too much information to be considered as Sculptural Symbolic Displays but not enough to be considered as Multiple Information Consolidators.

Table 12. Examples of displays that fall outside existing design patterns.

			Ranking 1 (low) …. 5 (high)			
Display	**Reference**	**Year**	Info Capacity	Notification Level	Representational Fidelity	Aesthetic Emphasis
Informative Art	[44]	2000	2	3	3	5
Mondrian Bus	[48]	2003	2	3	3	5
MoneyTree	[10]	2004	2	3	3	4
MoneyColor	[47]	2005	2	3	3	5
Butterfly / Dragonfly	[34]	2007	2	3	3	5
Fisherman	[47]	2007	2	3	3	5
Celling Display	[50]	2007	2	3	1	4
Rabbit screen display	[30]	2009	2	3	3	4
Virtual Aquarium	[32]	2013	2	4	3	4
Persuasive Art	[32]	2013	2	3	3	5

The unclassifiable displays typically have low information capacity, rely on metaphors for information transmission and are highly aesthetic. The examples of displays from the literature that embody these features (see table 12) are typically screen based and align to the goals of Informative Art, where only general awareness of the data is expected.

Table 13. Design Dimension mappings for the Aesthetic Information Display pattern [42]

Aesthetic Information Display	**Info Capacity**	**Notification Level**	**Representational Fidelity**	**Aesthetic Emphasis**
High				
Somewhat high				
Medium				
Somewhat low				
Low				

Due to the high number of displays that do not fit within the currently defined design types we propose a new design pattern we describe as the Aesthetic Awareness Display. Aesthetic Awareness Displays are highly aesthetic displays that display a moderate number of information sources to the user. Such systems use metaphors in order to encode data into the aesthetics of the display. Displays of this type are typically screen based but unlike Multiple Information Consolidators do not aim to deliver a high number of metrics to the user. Instead Aesthetic Information Displays focus on delivering a few metrics in an aesthetically pleasing display. In general, they represent a middle ground between Sculptural Symbolic Displays and Multiple Information consolidators.

6. CONCLUSION

In this paper we have reviewed the current state of design in the area of Ambient Information Systems, covering around 20 years of study since 1996. We have highlighted the various design dimensions that have been associated with Ambient Information Systems over this period. Focusing on the well-used Pousman & Stasko taxonomy of design patterns [42] we update previous work categorising displays using this taxonomy. As a result we highlight a large number of displays that fall outside existing design patterns. These displays fall somewhere between Sculptural Symbolic Displays and Multiple Information consolidators. We thus describe a new design pattern called an Aesthetic Awareness Display. These displays typically provide a few key metrics using metaphors that create an aesthetically pleasing display.

7. REFERENCES (Survey Paper)

[1] Alexander, C., Ishikawa, S. and Silverstein, M. 1977. Pattern languages. *Center for Environmental Structure*. 2, (1977).

[2] Ames, M. and Dey, A. 2002. *Description of design dimensions and evaluation for Ambient Displays*.

[3]Barrass, S. 2003. Sonification design patterns. (2003), 170--175.

[4] Brewer, J., Williams, A. and Dourish, P. 2005. Nimio: an ambient awareness device. (2005).

[5] Chang, A., Resner, B., Koerner, B., Wang, X. and Ishii, H. 2001. LumiTouch: an emotional communication device. (2001), 313--314.

[6] Consolvo, S., Roessler, P. and Shelton, B. 2004. The CareNet display: lessons learned from an in home evaluation of an ambient display. *Springer*. (2004), 1--17.

[7] Consumer Devices: 2015. *http://www.ambientdevices.com/about/consumer-devices*. Accessed: 2015- 05- 24.

[8] Dahley, A., Wisneski, C. and Ishii, H. 1998. Water lamp and pinwheels: ambient projection of digital information into architectural space. (1998), 269--270.

[9] Dey, A., Mankoff, J. and Dey, A. 2003. FROM CONCEPTION TO DESIGN, A Practical Guide to Designing Ambient Displays. *Citeseer*. (2003).

[10] Eades, P. and Shen, X. 2004. MoneyTree: ambient information visualization of financial data. (2004), 15--18.

[11] Fortmann, J., Stratmann, T., Boll, S., Poppinga, B. and Heuten, W. 2013. Make me move at work! An ambient light display to increase physical activity. (2013), 274--277.

[12] Fujinami, K. and Riekki, J. 2008. A case study on an ambient display as a persuasive medium for exercise awareness. *Springer*. (2008), 266--269.

[13] Furnas, G. 1986. *Generalized fisheye views*.

[14] Gamma, E., Helm, R., Johnson, R. and Vlissides, J. 1994. *Design patterns: elements of reusable object-oriented software*.

[15] Gustafsson, A. and Gyllenswärd, M. 2005. The power-aware cord: energy awareness through ambient information display. (2005), 1423--1426.

[16] Heiner, J., Hudson, S. and Tanaka, K. 1999. The information percolator: ambient information display in a decorative object. (1999), 141--148.

[17] Hinrichs, U., Fisher, D. and Riche, N. 2010. ResearchWave: An ambient visualization for providing awareness of research activities. (2010), 31--34.

[18] Ishii, H. and Ullmer, B. 1997. Tangible bits: towards seamless interfaces between people, bits and atoms. (1997), 234--241.

[19] Ishii, H., Wisneski, C., Brave, S., Dahley, A., Gorbet, M., Ullmer, B. and Yarin, P. 1998. ambientROOM: integrating ambient media with architectural space. (1998), 173--174.

[20] Jafarinaimi, N., Forlizzi, J., Hurst, A. and Zimmerman, J. 2005. Breakaway: an ambient display designed to change human behavior. (2005), 1945--1948.

[21] Kappel, K. and Grechenig, T. 2009. Show-me: water consumption at a glance to promote water conservation in the shower. (2009), 26.

[22] Kuribayashi, S. and Wakita, A. 2006. PlantDisplay: turning houseplants into ambient display. (2006), 40.

[23] Lee, K., Cho, H., Park, K. and Hahn, M. 2007. Ambient Lamp Display in the Active Home Ubiquitous Computing Environment for Relaxing and Mediation. (2007), 81--86.

[24] Mankoff, J., Dey, A., Hsieh, G., Kientz, J., Lederer, S. and Ames, M. 2003. Heuristic evaluation of ambient displays. (2003), 169--176.

[25] Matthews, T., Dey, A., Mankoff, J., Carter, S. and Rattenbury, T. 2004. A toolkit for managing user attention in peripheral displays. (2004), 247--256.

[26] Matthews, T., Rattenbury, T., Carter, S., Dey, A. and Mankoff, J. 2003. A peripheral display toolkit. *Computer Science Division, University of California*. (2003).

[27] McCrickard, D. and Chewar, C. 2003. Attuning notification design to user goals and attention costs. *Communications of the ACM*. 46, 3 (2003), 67--72.

[28] Messeter, J. and Molenaar, D. 2012. Evaluating ambient displays in the wild: highlighting social aspects of use in public settings. (2012), 478--481.

[29] Migicovsky, E. 2008. InfoPulse: a Wristworn Ambient Display. (2008), 1613--0073.

[30] Mirlacher, T., Buchner, R., FÃ¶rster, F., Weiss, A. and Tscheligi, M. 2009. *Ambient rabbits likeability of embodied ambient displays*.

[31] Mynatt, E., Rowan, J., Craighill, S. and Jacobs, A. 2001. Digital family portraits: supporting peace of mind for extended family members. (2001), 333--340.

[32] Nakajima, T. and Lehdonvirta, V. 2013. Designing motivation using persuasive

ambient mirrors. *Personal and ubiquitous computing*. 17, 1 (2013), 107--126.
[33] Nesbitt, K. 2005. Using guidelines to assist in the visualisation design process. (2005), 115--123.
[34] Nesbitt, K. and Shen, R. 2007. Butterfly/Dragonfly--An Ambient Display of Stock Market Data. *Journal of Engineering, Computing and Architecture*. 1, 1 (2007).
[35] Nesbitt, K. 2013. Simplicity: a design pattern for ideas. (2013). http://nova.newcastle.edu.au/vital/access/manager/Repository/uon:13440 *(Accessed June 15, 2015)*
[36] Ng, P. and Nesbitt, K. 2013. Informative sound design in video games. (2013), 9.
[37] Nielsen, J. 2005. Ten usability heuristics. *http://www. nngroup. com/articles/ten-usability-heuristics/ (Accessed December 19, 2013)*. (2005).
[38] Occhialini, V., van Essen, H. and Eggen, B. 2011. Design and evaluation of an ambient display to support time management during meetings. *Springer*. (2011), 263--280.
[39] Offenhuber, D. 2008. The Invisible Display-Design Strategies for Ambient Media in the Urban Context. (2008).
[40] Phelan, O., Coyle, L., Stevenson, G. and Neely, S. 2008. The Ambient Calendar. (2008).
[41] Pollack, I. and Pickett, J. 1957. Cocktail party effect. *The Journal of the Acoustical Society of America*. 29, 11 (1957), 1262--1262.
[42] Pousman, Z. and Stasko, J. 2006. A taxonomy of ambient information systems: four patterns of design. (2006), 67--74.
[43] Prante, T., RÃ¶cker, C., Streitz, N., Stenzel, R., Magerkurth, C., Van Alphen, D. and Plewe, D. 2003. Hello. wall--beyond ambient displays. (2003), 277--278.
[44] Redström, J., Skog, T. and HallnÃ¤s, L. 2000. Informative art: using amplified artworks as information displays. (2000), 103--114.
[45] Rogers, Y., Hazlewood, W., Marshall, P., Dalton, N. and Hertrich, S. 2010. Ambient influence: Can twinkly lights lure and abstract representations trigger behavioral change?. (2010), 261--270.
[46] Sekuler, R. and Blake, R. 1994. *Perception*. McGraw-Hill.
[47] Shen, X., Eades, P., Hong, S. and Moere, A. 2007. Intrusive and Non-intrusive Evaluation of Ambient Displays. (2007).
[48] Skog, T., Ljungblad, S. and Holmquist, L. 2003. Between aesthetics and utility: designing ambient information visualizations. (2003), 233--240.
[49] Stasko, J., Miller, T., Pousman, Z., Plaue, C. and Ullah, O. 2004. Personalized peripheral information awareness through information art. *Springer*. (2004), 18--35.
[50] Tomitsch, M., Grechenig, T. and Mayrhofer, S. 2007. Mobility and emotional distance: exploring the ceiling as an ambient display to provide remote awareness. *IET*. (2007).
[51] Valkanova, N., Moghnieh, A., Arroyo, E. and Blat, J. 2010. AmbientNEWS: augmenting information discovery in complex settings through aesthetic design. (2010), 439--444.
[52] Weiser, M. and Brown, J. 1996. Designing calm technology. *PowerGrid Journal*. 1, 1 (1996), 75--85.
[53] Wisneski, C., Ishii, H., Dahley, A., Gorbet, M., Brave, S., Ullmer, B. and Yarin, P. 1998. Ambient displays: Turning architectural space into an interface between people and digital information. *Springer*. (1998), 22--3

References

Ambientdevices.com,. (2015). *Energy Devices*. Retrieved 23 April 2015, from http://www.ambientdevices.com/about/energy-devices

Ames, M., & Dey, A. (2002). *Description of design dimensions and evaluation for Ambient Displays*.

Barrass, S. (2003). Sonification design patterns (pp. 170--175).

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation or novice researchers. The Qualitative Report, 13(4), 544--559.

Börner, K., & Polley, D. (2014). *Visual insights: A practical guide to making sense of data*.

Brenton, H., Gillies, M., Ballin, D., & Chatting, D. (2005). The uncanny valley: does it exist.

Brewer, J., Williams, A., & Dourish, P. (2005). Nimio: an ambient awareness device.

Bryman, A., & Bell, E. (2011). Business research methods. Cambridge: Oxford University Press.

C4Depot,. (2015). *Island Kit - Cinema 4D Scenery, Models & Tools*. Retrieved 5 July 2015, from http://c4depot.com/c4d-plugins/island-kit/

Card, S., Mackinlay, J., & Shneiderman, B. (1999). *Readings in information visualization: using vision to think*.

Chang, A., Resner, B., Koerner, B., Wang, X., & Ishii, H. (2001). LumiTouch: an emotional communication device (pp. 313--314).

Consolvo, S., Klasnja, P., McDonald, D., Avrahami, D., Froehlich, J., & LeGrand, L. et al. (2008). Flowers or a robot army?: encouraging awareness & activity with personal, mobile displays (pp. 54--63).

Consolvo, S., Roessler, P., & Shelton, B. (2004). The CareNet display: lessons learned from an in home evaluation of an ambient display. *Springer*, 1--17.

Dahley, A., Wisneski, C., & Ishii, H. (1998). Water lamp and pinwheels: ambient projection of digital information into architectural space (pp. 269--270).

Davis, F. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quarterly, 319--340.

DeFanti, T., Brown, M., & McCormick, B. (1989). Visualization: expanding scientific and engineering research opportunities. *Computer*, *22*(8), 12--25.

Dey, A., Mankoff, J., & Dey, A. (2003). FROM CONCEPTION TO DESIGN, A Practical Guide to Designing Ambient Displays. *Citeseer*.

Eades, P., & Shen, X. (2004). MoneyTree: ambient information visualization of financial data (pp. 15--18).

Eggen, B., & Van Mensvoort, K. (2009). Making sense of what is going on 'around': designing environmental awareness information displays. *Springer*, 99--124.

Fortmann, J., Stratmann, T., Boll, S., Poppinga, B., & Heuten, W. (2013). Make me move at work! An ambient light display to increase physical activity (pp. 274--277).

Fujinami, K., & Riekki, J. (2008). A case study on an ambient display as a persuasive medium for exercise awareness. *Springer*, 266--269.

Furnas, G. (1986). *Generalized fisheye views*.

Gamma, E., Helm, R., Johnson, R., & Vlissides, J. (1994). *Design patterns: elements of reusable object-oriented software*.

Google Developers,. (2015). *What Is The Real Time Reporting API - Overview*. Retrieved 4 July 2015, from https://developers.google.com/analytics/devguides/reporting/realtime/v3/

Google.com,. (2015). *Google Analytics Official Website" Web Analytics & Reporting*. Retrieved 4 July 2015, from http://www.google.com/analytics

Göransson, B., Gulliksen, J., & Boivie, I. (2003). The usability design process--integrating user-centered systems design in the software development process. *Software Process: Improvement And Practice*, *8*(2), 111--131.

Gustafsson, A., & Gyllenswärd, M. (2005). The power-aware cord: energy awareness through ambient information display (pp. 1423--1426).

Hallnäs, L., & Redström, J. (2001). Slow technology--designing for reflection. *Personal And Ubiquitous Computing*, *5*(3), 201--212.

Hancock, D., & Algozzine, R. (2006). Doing case study research. New York: Teachers College Press.

Harris, R. (1999). *Information graphics: A comprehensive illustrated reference*.

Heiner, J., Hudson, S., & Tanaka, K. (1999). The information percolator: ambient information display in a decorative object (pp. 141--148).

Hendley, R., Drew, N., Wood, A., & Beale, R. (1995). Case study. Narcissus: visualising information (pp. 90--96).

Hinrichs, U., Fisher, D., & Riche, N. (2010). ResearchWave: An ambient visualization for providing awareness of research activities (pp. 31--34).

Holmquist, L., & Skog, T. (2003). Informative art: information visualization in everyday environments (pp. 229--235).

Inselberg, A. (1997). Multidimensional detective (pp. 100--107).

Ishii, H., & Ullmer, B. (1997). Tangible bits: towards seamless interfaces between people, bits and atoms (pp. 234--241).

Ishii, H., Wisneski, C., Brave, S., Dahley, A., Gorbet, M., Ullmer, B., & Yarin, P. (1998). ambientROOM: integrating ambient media with architectural space (pp. 173--174).

Ishikawa, S., & Silverstein, M. (1977). *A pattern language: towns, buildings, construction*.

Jafarinaimi, N., Forlizzi, J., Hurst, A., & Zimmerman, J. (2005). Breakaway: an ambient display designed to change human behavior (pp. 1945--1948).

Jameson, D. (1994). Sonnet: Audio-enhanced monitoring and debugging (pp. 253--253).

Johnson, B., & Shneiderman, B. (1991). Tree-maps: A space-filling approach to the visualization of hierarchical information structures (pp. 284--291).

Kappel, K., & Grechenig, T. (2009). Show-me: water consumption at a glance to promote water conservation in the shower (p. 26).

Keim, D., & Kriegel, H. (1994). VisDB: Database exploration using multidimensional visualization. *Computer Graphics And Applications, IEEE*, *14*(5), 40--49.

Kollender, J. (2014). *Wave Deformer for C4D. Vimeo*. Retrieved 5 July 2015, from https://vimeo.com/91515753

Kramer, G. (1994). An introduction to auditory display (pp. 1--77).

Kuribayashi, S., & Wakita, A. (2006). PlantDisplay: turning houseplants into ambient display (p. 40).

Lamping, J., & Rao, R. (1996). The hyperbolic browser: A focus+ context technique for visualizing large hierarchies. *Journal Of Visual Languages & Computing*, *7*(1), 33--55.

Lee, K., Cho, H., Park, K., & Hahn, M. (2007). Ambient Lamp Display in the Active Home Ubiquitous Computing Environment for Relaxing and Mediation (pp. 81--86).

Madhyastha, T., & Reed, D. (1994). A framework for sonification design (pp. 267--267).

Mankoff, J., Dey, A., Hsieh, G., Kientz, J., Lederer, S., & Ames, M. (2003). Heuristic evaluation of ambient displays (pp. 169--176).

Matthews, T., Dey, A., Mankoff, J., Carter, S., & Rattenbury, T. (2004). A toolkit for managing user attention in peripheral displays (pp. 247--256).

Matthews, T., Rattenbury, T., Carter, S., Dey, A., & Mankoff, J. (2003). A peripheral display toolkit. *Computer Science Division, University Of California*.

Maxon.net,. (2015). *MAXON | 3D FOR THE REAL WORLD: Overview*. Retrieved 4 July 2015, from http://www.maxon.net/en/products/new-in-cinema-4d-r16/overview.html

McCabe, K., & Rangwalla, A. (1994). Auditory display of computational fluid dynamics data (pp. 327--327).

McCrickard, D., & Chewar, C. (2003). Attuning notification design to user goals and attention costs. *Communications Of The ACM*, *46*(3), 67--72.

McCrickard, D., Catrambone, R., & Stasko, J. (2001). Evaluating animation in the periphery as a mechanism for maintaining awareness (pp. 148--156).

McCrickard, D., Chewar, C., Somervell, J., & Ndiwalana, A. (2003). A model for notification systems evaluationâ€"assessing user goals for multitasking activity. *ACM Transactions On Computer-Human Interaction (TOCHI)*, *10*(4), 312--338.

Messeter, J., & Molenaar, D. (2012). Evaluating ambient displays in the wild: highlighting social aspects of use in public settings (pp. 478--481).

Microsoft.com,. (2015). *SQL Server 2014 | Microsoft*. Retrieved 5 July 2015, from http://www.microsoft.com/en-au/server-cloud/products/sql-server/

Migicovsky, E. (2008). InfoPulse: a Wristworn Ambient Display (pp. 1613--0073).

Miller, T., & Stasko, J. (2001). The InfoCanvas: information conveyance through personalized, expressive art (pp. 305--306).

Mirlacher, T., Buchner, R., Förster, F., Weiss, A., & Tscheligi, M. (2009). *Ambient rabbits likeability of embodied ambient displays*.

Msdn.microsoft.com,. (2015). *MediaElement Class (System.Windows.Controls)*. Retrieved 5 July 2015, from https://msdn.microsoft.com/en-us/library/system.windows.controls.mediaelement(v=vs.110).aspx

Msdn.microsoft.com,. (2015). *Windows Presentation Foundation*. Retrieved 4 July 2015, from https://msdn.microsoft.com/en-us/library/ms754130(v=vs.110).aspx

Mynatt, E., Back, M., Want, R., Baer, M., & Ellis, J. (1998). Designing audio aura (pp. 566--573).

Mynatt, E., Rowan, J., Craighill, S., & Jacobs, A. (2001). Digital family portraits: supporting peace of mind for extended family members (pp. 333--340).

Nakajima, T., & Lehdonvirta, V. (2013). Designing motivation using persuasive ambient mirrors. *Personal And Ubiquitous Computing*, *17*(1), 107--126.

Nesbitt, K. (2000). A classification of multi-sensory metaphors for understanding abstract data in a virtual environment (pp. 493--498).

Nesbitt, K. (2001). Modeling the multi-sensory design space (pp. 27--36).

Nesbitt, K. (2002). Experimenting with haptic attributes for display of abstract data.

Nesbitt, K. (2005). Using guidelines to assist in the visualisation design process (pp. 115--

123).

Nesbitt, K., & Barrass, S. (2002). Evaluation of a multimodal sonification and visualisation of depth of market stock data. *Georgia Institute Of Technology*.

Nesbitt, K., & Shen, R. (2007). Butterfly/Dragonfly--An Ambient Display of Stock Market Data. *Journal Of Engineering, Computing And Architecture*, *1*(1).

Nesbitt KV. Simplicity - A Design Pattern for Ideas. Applied Informatics Research Group Working Paper Series, Number 3 (3). Sep 2013. University of Newcastle. 1-19, http://hdl.handle.net/1959.13/1037500

Ng, P., & Nesbitt, K. (2013). Informative sound design in video games (p. 9).

Nielsen, J. (1990). *Designing user interfaces for international use*.

Nielsen, J. (2005). Ten usability heuristics. *Http://Www. Nngroup. Com/Articles/Ten-Usability-Heuristics/(Accessed December 19, 2013)*.

Occhialini, V., van Essen, H., & Eggen, B. (2011). Design and evaluation of an ambient display to support time management during meetings. *Springer*, 263--280.

Offenhuber, D. (2008). The Invisible Display-Design Strategies for Ambient Media in the Urban Context.

Phelan, O., Coyle, L., Stevenson, G., & Neely, S. (2008). The Ambient Calendar.

Pollack, I., & Pickett, J. (1957). Cocktail party effect. *The Journal Of The Acoustical Society Of America*, *29*(11), 1262--1262.

Poslad, S. (2009). Ubiquitous computing smart devices, smart environments and smart interaction. *Chippenham: Wiley*.

Pousman, Z., & Stasko, J. (2006). A taxonomy of ambient information systems: four patterns of design (pp. 67--74).

Prante, T., Röcker, C., Streitz, N., Stenzel, R., Magerkurth, C., Van Alphen, D., & Plewe, D. (2003). Hello. wall--beyond ambient displays (pp. 277--278).

Preece, J., Rogers, Y., & Sharp, H. (2002). *Interaction design*. New York, NY: J. Wiley & Sons.

Realflow.com,. (2015). *RealFlow Home*. Retrieved 5 July 2015, from http://realflow.com

Redström, J., Skog, T., & Hallnäs, L. (2000). Informative art: using amplified artworks as information displays (pp. 103--114).

Reitberger, W., Obermair, C., Ploderer, B., Meschtscherjakov, A., & Tscheligi, M. (2007). Enhancing the shopping experience with ambient displays: a field study in a retail store. *Springer*, 314--331.

Rogers, Y., Hazlewood, W., Marshall, P., Dalton, N., & Hertrich, S. (2010). Ambient influence: Can twinkly lights lure and abstract representations trigger behavioral change? (pp. 261--270).

Schmidt, A., Gellersen, H., & Beigl, M. (1999). Matching information and ambient media. *Springer*, 140--149.

Sekuler, R., & Blake, R. (1994). *Perception*. New York: McGraw-Hill.

Shen, X. (2007). An Evaluation Methodology for Ambient Displays. *Journal Of Engineering, Computing And Architecture*, *1*(2).

Shen, X., & Eades, P. (2005). Using MoneyColor to represent financial data (pp. 125--129).

Shen, X., Eades, P., Hong, S., & Moere, A. (2007). Intrusive and Non-intrusive Evaluation of Ambient Displays.

Shneiderman, B. (1992). *Designing the user interface: strategies for effective human-computer interaction*.

Skog, T., Ljungblad, S., & Holmquist, L. (2003). Between aesthetics and utility: designing ambient information visualizations (pp. 233--240).

Stake, R. (1995). The art of case study research. Thousand Oaks: Sage Publications.

Stasko, J., Miller, T., Pousman, Z., Plaue, C., & Ullah, O. (2004). Personalized peripheral information awareness through information art. *Springer*, 18--35.

Tomitsch, M., Grechenig, T., & Mayrhofer, S. (2007). Mobility and emotional distance: exploring the ceiling as an ambient display to provide remote awareness. *IET*.

Tomitsch, M., Kappel, K., Lehner, A., & Grechenig, T. (2007). Towards a taxonomy for ambient information systems (pp. 42--47).

Tsukada, K., & Masui, T. (2006). *PhantomParasol: a parasol-type display transitioning from ambient to detailed*.

Tufte, E. (1991). Envisioning information. *Optometry & Vision Science*, *68*(4), 322--324.

Tufte, E., & Graves-Morris, P. (1983). *The visual display of quantitative information*.

Tufte, E., & Weise Moeller, E. (1997). *Visual explanations: images and quantities, evidence and narrative*.

Valkanova, N., Moghnieh, A., Arroyo, E., & Blat, J. (2010). AmbientNEWS: augmenting information discovery in complex settings through aesthetic design (pp. 439--444).

Weiser, M. (1991). The computer for the 21st century. *Scientific American*, *265*(3), 94--104.

Weiser, M., & Brown, J. (1996). Designing calm technology. *Powergrid Journal*, *1*(1), 75--85.

Weiser, M., & Brown, J. (1997). The coming age of calm technology. *Springer*, 75--85.

Wilson, S. (2002). *Information arts: intersections of art, science, and technology*.

Wise, J., Thomas, J., Pennock, K., Lantrip, D., Pottier, M., Schur, A., & Crow, V. (1995). Visualizing the non-visual: spatial analysis and interaction with information from text documents (pp. 51--58).

Wisneski, C., Ishii, H., Dahley, A., Gorbet, M., Brave, S., Ullmer, B., & Yarin, P. (1998). Ambient displays: Turning architectural space into an interface between people and digital information. *Springer*, 22--32.

Yin, R. (1989). Case study research. Newbury Park [Calif.]: Sage Publications.

Yin, R. (2003). Case study research. Thousand Oaks, Calif.: Sage Publications.